

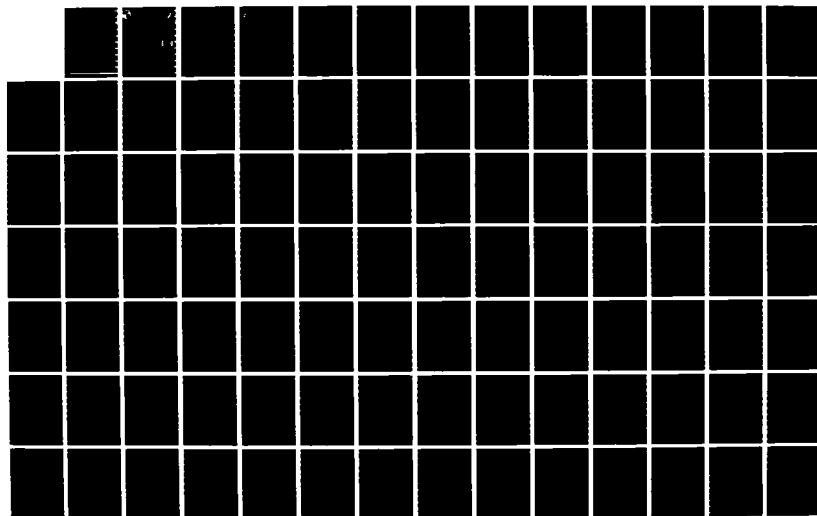
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OPTICAL TURBULENCE MEASUREMENT - INVESTIGATION FOR
ANALYSIS OF LASER DESI. (U) ARMY ELECTRONIC PROVING
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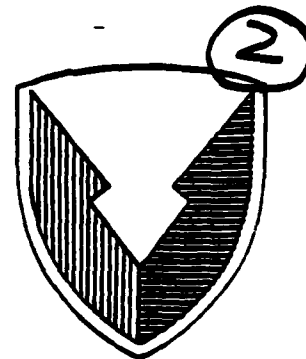
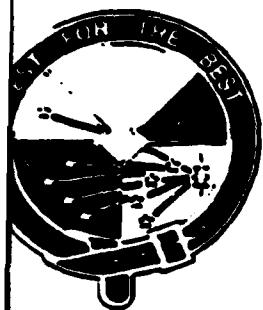
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METHODOLOGY INVESTIGATION

FINAL REPORT

OPTICAL TURBULENCE MEASUREMENT - INVESTIGATION FOR ANALYSIS
OF LASER DESIGNATOR SPOT PATTERNS - PHASE II (FIELD TEST)

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ABERDEEN PROVING GROUND, MARYLAND 21005-5006

AMSTE-TC-M

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SUBJECT: Final Report on Optical Turbulence Measurement - Investigation for
Analysis of Laser Designator Spot Patterns - Phase II (Field Test),
TECOM Project No. 7-CO-RD4-EP0-006

Commander
U.S. Army Electronic Proving Ground
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FOR THE COMMANDER:

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This methodology investigation evaluates the feasibility of applying video instrumentation and image analysis techniques to characterize optical path turbulence for use in assessing the field performance of laser designator systems. The effort focused on adapting a C_n^2 path weighted measurement technique developed by Dr. E. Crittenden, NPS, which uses a tele- scope mechanical slit scanner configuration for data acquisition. Phase I of the investi- gation covered a theoretical analysis, software development, and laboratory measurements. The Phase II effort presented in this report covers the conduct of a limited field test to validate the data acquisition and data analysis process developed during Phase I of the investigation. The field test involved making C_n^2 measurements with the original NPS slit scanner equipment and a video C_n^2 data acquisition system. Smoke was also introduced in the optical path. The amount of test data taken was limited by severe rainstorms which occurred during a normally dry season at the test site. The test results showed a correlation of 0.81 between the data collected by the two measurement systems.					
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This was less than expected and was attributed to variances in focus adjustment and video saturation level control. Improvements in the adjustment and control of these measurement parameters should increase the correlation level. The smoke from a phosphorus smoke grenade did not produce any significant changes to the path C_n^2 . However, smoke from the burning of the rubber residue of the smoke grenade did produce a significant change to the path C_n^2 . The report includes the video data processing computer programs for generating the C_n^2 data.

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FOREWORD

The US Army Electronic Proving Ground was responsible for the execution of this project. Mr. C. M. Giorgi was the USAEPG Project Officer with assistance from Mr. L. Butler and 1LT G. Christman. Technical guidance, as well as the idea for the project, was provided by the Test and Evaluation Command Project Officer, Dr. N. E. Pentz.

Dr. E. A. Milne and Dr. E. C. Crittenden of the Naval Postgraduate School, Monterey, California, were responsible for the overall technical direction of the project, to include test planning, data acquisition, and data analysis. The material presented in the body of this report primarily reflects the results of their work as documented by Dr. Milne.

Dr. J. Engel and Mr. R. Ransier, Bell Technical Operations, Textron, Tucson, Arizona, provided support for the operation of the video data acquisition systems and analysis of the video data. The documentation covering the video data acquisition, processing, and the associated computer programs was prepared by Dr. Engel.

Mr. E. Burgess of the Dugway Proving Ground, Utah, provided the smoke expertise for the project and also directed its deployment during the test.



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SECTION 1. SUMMARY

1.1 BACKGROUND

a. The spot patterns produced by laser designators suffer from a number of defects. The patterns are broadened and exhibit wander and intensity fluctuation because of turbulence in the atmosphere. Designator spot patterns also exhibit similar defects because of internal laser instability and motion of the transmitter platform. In order to correct the latter defects, a system is needed that is capable of separating the contributions of the several effects.

b. Investigative effort at the Naval Postgraduate School (refs 1, 2, and 3, app G) and elsewhere (ref 4, app G) previously demonstrated that the effects of atmospheric turbulence on designator spot patterns can be expressed in terms of the Optical Transfer Function (OTF) of the atmosphere. This quantity is the Fourier transform of the spot profile due to the atmosphere alone. If other causes of spot broadening such as laser instability and platform motion are present, the spot profile will be the convolution of the spot profiles due to each of the effects. The spot profile broadening, due to laser and platform instability, can then be separated from the atmospheric effects by dividing the Fourier transform of the spot profile by the OTF of the atmosphere (point-by-point as a function of spatial frequency). The necessary OTF of the atmosphere can be obtained by means of a slit-scanning telescope system which views a point laser in the target vicinity from a location near the designator transmitter. An additional imaging system, viewing the designator spot on a target screen, from a location near the target, yields the composite spot profile. Data from this imager, together with that from the telescope imager at the transmitter site, can separate the various effects. However, because designator lasers use short pulses, the previously developed mechanical slit-scan techniques cannot be used. Storage imaging systems, using VIDICON, CCD, or CID techniques, are needed to sense the image for the very short pulse periods and provide the equivalent of a slit-scan during the interpulse period.

c. A study and experimental investigation to evaluate and demonstrate the feasibility of the video technique was accomplished as Phase I of this investigation. The results of the Phase I effort are reported in references 7 and 8, appendix G. The feasibility of the technique was demonstrated and a test plan to evaluate the technique under field conditions was proposed as a followup effort (See app E). This report covers the results of that field test or Phase II of the investigation.

1.2 OBJECTIVES

a. To compare atmospheric turbulence measurements made with a mechanical slit scan telescope system to those made with a video imaging system.

b. To develop and document video data reduction and analysis procedures and software for measuring atmospheric turbulence.

c. Apply the measured field data to account for the effects of atmospheric turbulence on the performance of a ground-based laser designator.

1.3 SUMMARY OF PROCEDURES

a. Test Period. The field tests were conducted on 10, 11, and 12 September 1984. With regard to the test schedule, the conduct of the field test involved the application of instrumentation and personnel resources which were also being utilized to support the ongoing Remotely Piloted Vehicle (RPV) test program at USAEPG. Consequently scheduling of the lower priority methodology project produced a series of postponements during the investigative period to include having to eventually schedule around the July-August monsoon season in southern Arizona. As it turned out, in consonance with one of Murphy's Laws, the first two days of the test produced all-time record rainfall for those days.

b. Test Site. The test site was on the West Range, Fort Huachuca, at a location previously used for a "Smoke Week" test program. The site was chosen for its clear line-of-sight path and the availability of a large roofed instrumentation platform.

c. Instrumentation Configuration. The general configuration is described in the test plan (app E). The specific video measurement setup and equipment used in the field test is shown in figure 1. The MTF measuring instrumentation was stationed on a large platform. However, the vibration sensitivity of the measurement systems required the use of a separate platform for the scanning telescope and video camera/telescope units which were mounted on tripods. The extension platform which was weighted down with sandbags served to isolate the vibration caused by personnel movement on the main platform.

d. Test Procedures: The test procedures are described in the test plan. Preliminary checkout of all test instrumentation was accomplished on the morning of 10 September. Comparison data was acquired on the 11th and smoke testing completed September 12th. A malfunction of the laser-designator simulator, which had just undergone a factory checkout, precluded acquiring data for the designator spot analysis application part of the field test. The video data was recorded and later processed using programs originally written by Dr. E. Milne of NPS for an IBM system and adapted for the HP 1000 by Dr. J. Engel of Bell Technical Operations. The data from the NPS system was processed on-site in near real time using a dedicated microprocessor. The test data acquisition and analysis processes are further described in Section 2 and in appendices A through D. The appendices include a complete description of the computer programs used for the data reduction and analysis and provide a user-type manual for applying the technique to support electro-optical field measurements.

e. Test Conditions. As noted above, the weather did not cooperate during the brief opening in the availability of the test support resources. However, on the positive side, the three days did include a range of clear to very cloudy conditions and a larger than normal range of ambient temperatures due to the uncharacteristic rain squalls.

1.4 SUMMARY OF RESULTS

a. Although the total amount of test data was restricted by the weather conditions, the limited results demonstrated that a video system, viewing a HeNe laser, can be used to measure C_n^2 if care is taken to avoid saturation of the video signal.

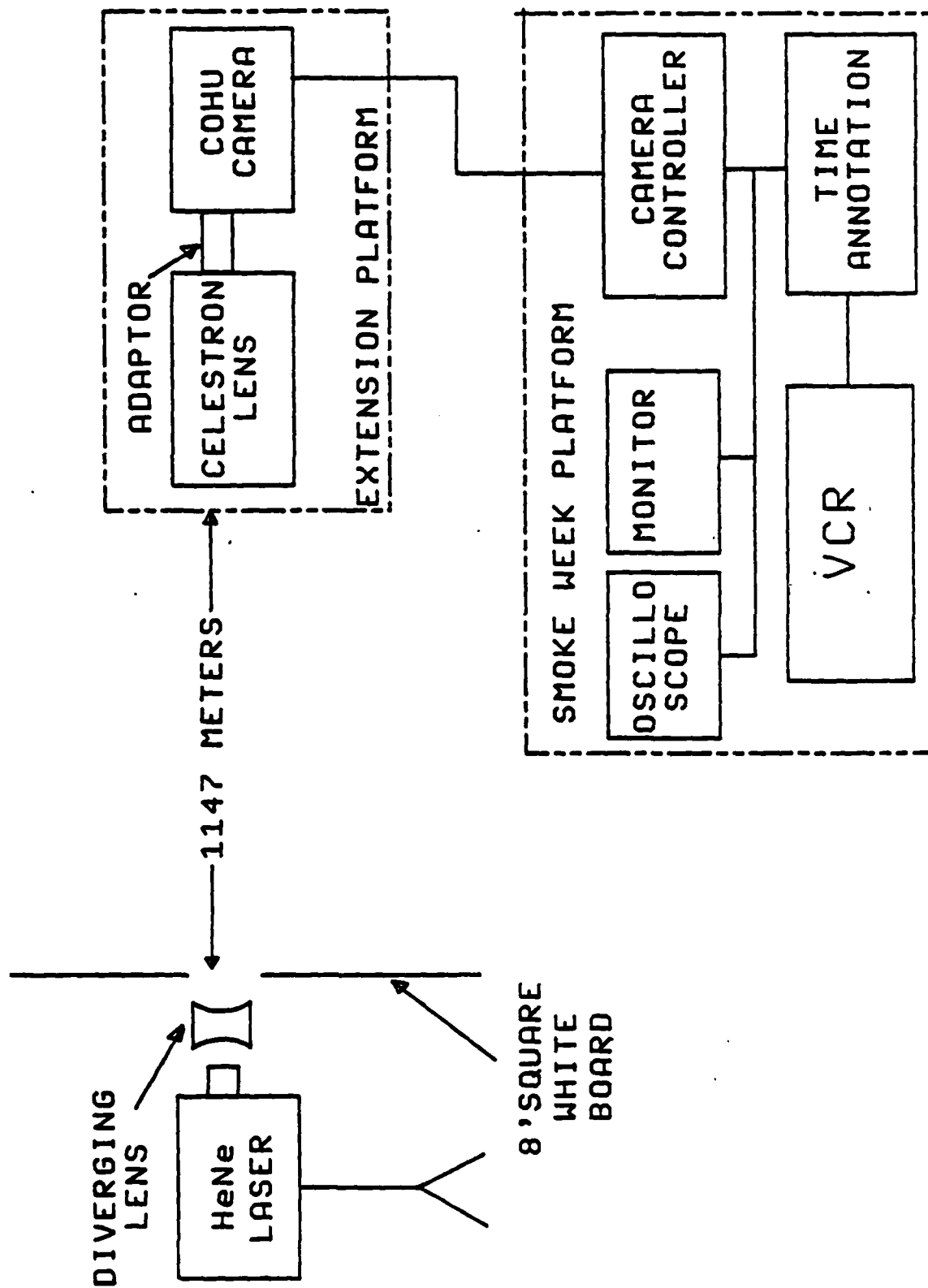


Figure 1. Data acquisition setup.

(2) A C_n^2 data analysis program for the video system which runs on the HP 1000 has been developed and documented. This capability will allow transfer of the technology to a number of potential users.

c. No experimental results of applying the data for laser designator performance analysis were obtained due to the malfunction of the designator simulator.

1.5 ANALYSIS

a. Comparison of Results. Although there were differences in the two measurements, the C_n measured by the NPS slit-scan system and the C_n measured by the video system had a correlation coefficient of 0.81. This is not as good as one would like but it indicates that the two systems are measuring essentially the same thing. The lack of better correlation can be attributed to several problems; one, the video signal is subject to saturation which will give unpredictable results; two, the focus of the two systems will give larger C_n values if out of adjustment; three, the vibrations of the platform will give higher results for the wander and the long-term measurements.

b. Problems with the TV System

(1) Some observations with the video system showed problems that should be corrected if the system is to be used effectively. First, the mounting of the camera and the telescope should allow easy access to the adjustments of the polaroids; second, a measurement of the OTF of the video optical system should be carefully made in the laboratory before any calculations are made. The diffraction limit OTF was used in these calculations; third, the vibrations of the platform due to the wind were evident because the C_n , as measured from the wander, was consistently high in both the slit-scan system and the video system. The platform was braced with diagonal 2 x 4s but this did not completely stop the vibration by the wind.

(2) The video system needed a spotting scope on the telescope for alignment and a way to adjust the polaroids without taking the system apart. The ability to adjust the polaroids is very important because the dynamic range of the video system is rather small. This often leads to saturation of the signal from the video system if the intensity of the laser spot is too high; small changes in the extinction or C_n^2 will require that the setting be changed to prevent wash-out of the signal if the intensity is too low or saturation of the signal if the intensity is too high.

c. Video System Viewing a Distant Laser

(1) The tests show that a video system viewing a distant laser could be used for making measurements on the atmospheric modulation transfer function (MTF). However, there are some details that must be resolved before such a system can work reliably in the field.

(2) The first of these is the focus of the telescope, which must be accurately adjusted for the best focus. If the system is not in focus, the measured values of OTF will be high, especially during periods of low turbulence. This was not much of a problem for this test since the laser source and the telescope and video system were at fixed positions and sufficient time to adjust for the best focus. However, if either the laser or the video system is on a moving platform, the focus must be continually adjusted. Associated with this is the need to know the range, which is necessary for the calculation of the OTF.

(3) Another detail is the fact that the video system has a very low dynamic range between the noise level and the maximum intensity before saturation. A normal video system uses different f-stops to adjust the light level, but this would require a different system OTF for every f-stop. Crossed polaroids were used for this test which seemed to work well except as mentioned above; they were not accessible for easy adjustment. As a result, during periods of low turbulence the light level of the laser spot on the video signal became too high and needed to be adjusted. This was overlooked on part of the test and gave anomalous results such as a negative OTF.

(4) The problem of a moving platform can be overcome by using only the short-term calculations. Even with the telescopes on a separate platform, there was enough motion of the platform to be noticeable in the wander measurements when the wind was blowing. If a platform is being used, such as a helicopter, a tracking system may be necessary to keep the telescope pointed at the laser.

(5) With regard to data turnaround, the test demonstrated the need for near real time processing of the video data. With the currently available powerful and inexpensive microcomputers, the video data could easily be processed on a near real time basis with a dedicated unit.

d. Comments on a Video System Observing a Laser Designator

(1) This part of the test was not run because the laser designator simulator did not operate during the test. However, a comment can be made about the probable results of such a system. The divergence of the laser designator beam must not be greater than twice the divergence due to the atmosphere on a turbulent day which is on the order of 50 microradians, in order to be able to make measurements of C_n^2 . It may be possible to infer the C_n^2 from the spatial distribution of the intensity about the center of the designator spot on the target.

(2) Because of the failure of the laser designator simulator to operate, no experimental results were obtained with the designator. Theoretical calculations indicate that a video system viewing a laser designator spot should work to separate out the effects of turbulence, internal laser instability, and platform motion, provided that the beam divergence of the designator is of the order of 100 microradians or less. That is, the spot on a target 1 kilometer away should be of the order of 10 centimeters or less in diameter. Also the video system viewing the target should be close enough so that the image of the spot is at least 15 to 20 pixels in diameter.

1.6 CONCLUSIONS

a. The comparison tests of the NPS split-scan system with the video system demonstrated that a video system viewing a HeNe laser at 0.5 to 2 kilometers distance can be used to measure the OTF of the atmosphere if care is taken to avoid saturation in the vidicon tube and that the best focus is maintained.

b. A video system for viewing laser designator spots can be used to separate the effects on laser designators of atmospheric turbulence, internal laser designator instability, and platform motion, provided the divergence of the designator beam is less than about 100 microradians when there is no atmospheric turbulence. The effects of the turbulent atmosphere will be less than about 50 microradians which amounts to about 5 cm at the target 1 km away. This is likely to be much smaller than the effects of motion of the platform.

1.7 RECOMMENDATION

If a video system is built for measuring the OTF of the atmosphere, it is recommended that it include a system for obtaining the best focus, a feedback system for preventing saturation of the vidicon tube, and an on-line micro-computer system for immediate data reduction.

SECTION 2. DETAILS OF INVESTIGATION (FIELD TEST)

2.1 EQUIPMENT DESCRIPTION

a. CW Laser Source. A 1-milliwatt helium-neon laser source ($\lambda = 0.6328$ micrometers) was positioned 1147 meters downrange from the platform as measured by a laser ranging system. The laser was mounted on a tripod and pointed directly at the camera on the observation platform. In front of the laser was an 8-foot-square board painted white with a small hole in the center as a passthrough for the laser beam. A diverging lens was used to reduce the intensity of the laser and to provide a uniform intensity cross section at the observation point. To ensure that the center of the laser beam fell upon the camera, the outer edges of the beam were visually located at the observation area, and the laser was moved so that these points were equidistant from the camera. The beam's divergence was about 20 milliradians.

b. Video System. A Cohu 7210B camera, incorporating an extended range silicon diode array vidicon, was used to observe the laser beam. The front end optics included a Celestron 2000-millimeter f/10 Cassegrain lens and an adapter for joining the lens and the camera. The adapter, manufactured by the NPS, consists of a 1.55X Barlow lens, a 0.6328-micrometer interference filter, and a pair of adjustable polarizers for setting the illuminance of the vidicon. This camera assembly was mounted on a tripod and positioned on a small platform in front of, and separate from, the Smoke Week platform to ensure vibration isolation. The camera control unit was used to adjust the level of the video signal from the camera. Care had to be taken that this level was not above the clipping level of the camera system. Thus, the video levels were continuously monitored with an oscilloscope. The video signal was recorded on a 3/4-inch format Panasonic video cassette recorder. Time and date annotations were inserted on the video signal prior to recording.

c. NPS Slit Scanning System. The system consists of a Celestron 8-inch diameter Schmidt telescope with an equivalent focal length of 160 inches with a times 2 Barlow lens. It has a central obscuration ratio of 0.344. The telescope is equipped with up-down and right-left tracking, and linear scan across a slit, for generating the line-spread function. The field lenses pass the light through a narrowband interference filter before falling on the detector, which is a GE silicon avalanche multiplier. The auxiliary equipment includes the scan servos, amplifiers, and on-line data processing equipment. The total package occupies a volume of about that of an office desk.

d. Equipment Checkout. The preliminary setup and equipment check-out occurred in the morning of 10 September 1984. The measurements made on the uncalibrated system were satisfactory. The calibration was deferred until the following morning when the scintillation was likely to be low. A multisensor meteorological station was located at the test site to provide meteorological data. A severe storm developed in the early afternoon which terminated further checkout and required the disassembly of the equipment. It had been planned to obtain photo coverage of the test site and the instrumentation. Unfortunately the adverse weather and the photographer showed up at the same time each day.

2.2 MEASUREMENTS OF 11 SEPTEMBER 1984

On 11 September, test setup was initiated at 0600. The systems were calibrated and the first measurements were made at 0748. The weather started out clear but by 0800 it was partly cloudy. It continued to cloud up until it was mostly cloudy by 0900. It started to rain by noon and the storm lasted all afternoon with very heavy rains. No data were taken in the afternoon. A listing of the data is shown in Table I.

TABLE I. DATA TAKEN ON 11 SEPTEMBER 1984

Time	Conditions	C _n (LT)	C _n (ST)	C _n (Wan)
0747	partly cloudy	3.036e-07	---	---
0750	partly cloudy	---	3.795e-07	---
0803	cloudy	1.733e-07	---	---
0805	cloudy	---	2.152e-07	1.049e-07
0824	cloudy	2.174e-07	---	---
0827	cloudy	2.880e-07	---	---
0846	full sun	4.488e-07	---	---
0847	full sun	---	5.125e-07	2.814e-07
0859	partly cloudy	3.346e-07	---	---
0900	partly cloudy	---	4.221e-07	2.929e-07
0916	cloudy	3.394e-07	---	---
0918	part sun	---	4.121e-07	3.316e-07
1011	part sun	4.121e-07	---	---
1013	windy	---	4.085e-07	8.053e-07 (wind?)
1044	cloudy	2.571e-07	---	---
1045	cloudy and wind	---	2.045e-07	3.535e-07
1102	cloudy and wind	1.199e-07	---	---

No data for the video system were reduced for data taken on 11 September 1984.

2.3 MEASUREMENTS OF 12 SEPTEMBER 1984 INCLUDING SMOKE TEST

On 12 September, test setup began at 0615. Except for a delay -- the generator at the laser end of the range ran out of gas -- everything was ready to take data by 0730. The first measurements were made just before 0900. The weather was sunny during the morning, then became partly cloudy in the early afternoon, and finally, cloudy later in the afternoon. A crosswind blew most of the afternoon. The wind was often strong enough to cause a vibration of the platform holding the telescopes. This showed up in the measurements of long

term and wander. No long-term measurements were made during the rest of the afternoon. Since the wander measurements are very sensitive to vibration, they give an indication of the wind. The separate platform did isolate the telescopes from the vibrations due to people moving about on the main platform, but the wind caused vibrations which affected the wander and the long-term measurements. A little rain fell between 1245 and 1330, then it started to rain again after 1630. The smoke tests were made after 1130. There was no apparent effect of the smoke from the grenades except for increasing the extinction. After 1600, black smoke from burning rubber was tested. This smoke definitely increased the effective C_n that was measured. This was also observed qualitatively with the video system. Video recordings were made throughout the day on September 12 at roughly half-hour intervals. Twice during the day, in periods of low turbulence, a diffraction grating was held in front of the camera optics and recordings were made of the laser spot diffraction pattern. The data provided scaling information used in the analysis performed later. A total of about 2-1/2 hours of video data was obtained during the 2 days of data collection. The data taken on 12 September is shown in Table II.

Efforts were made to operate the laser designator but it behaved erratically, hence, measurements using the laser designator were not accomplished.

TABLE II. TESTS PERFORMED ON 12 SEPTEMBER 1984.

Time	Conditions	C_n (LT)	C_n (ST)	C_n (Wan)	Smoke
0855	Clear	2.481e-07	---	---	No
0859	Clear	3.346e-07	---	---	No
0900*	Clear	2.828e-07	2.205e-07	2.989	No
0900	Sunny	---	2.955e-07	---	No
0902	Sunny	---	3.128e-07	3.465e-07	No
0930*	Sunny	3.447e-07	2.976e-07	8.595e-07	No
0931	Sunny	3.406e-07	3.840e-07	3.326e-07	No
0957	Sunny	3.981e-07	3.934e-07	3.297e-07	No
1001	Sunny	4.199e-07	4.300e-07	3.304e-07	No
1001*	Sunny	4.127e-07	2.855e-07	1.824e-06	No
1039	Sunny	4.752e-07	4.553e-07	4.970e-07	No
1039*	Sunny	3.801e-07	3.122e-07	1.317e-06	No
1100	Some grenade set off 15 m upwind from beam and 114 meters down range from telescopes.				

*Indicates video data.

TABLE II. TESTS PERFORMED ON 12 SEPTEMBER 1984 (CONT)

Time	Conditions	C _n (LT)	C _n (ST)	C _n (Wan)	Smoke
1106		4.293e-07	---	---	Yes
1108		3.842e-07	---	---	Yes
1110		4.458e-07	---	---	Yes
1110*	Prtly Cloudy	3.494e-07	3.068e-07	1.236e-07	Yes
1112	Prtly Cloudy	4.458e-07	---	---	Yes
1113	Prtly Cloudy	4.443e-07	---	---	Yes
1130	Cloudy	1.686e-07	---	---	Yes
1130*	Cloudy	2.518e-07	2.240e-07	5.485e-07	Yes
1131	Clearing	1.936e-07	---	---	Yes
1132	Prtly Cloudy	2.998e-07	---	---	Yes
1133	Sunny	3.698e-07	---	---	Yes
1134	Sunny	3.590e-07	---	---	Yes
1135	Sunny	4.574e-07	---	---	Yes
1136	Prtly Cloudy	4.468e-07	---	---	Yes
1137	Mstly Cloudy	3.983e-07	---	---	Yes
1138	Cloudy	3.835e-07	---	---	Yes
1139	Cloudy	3.007e-07	---	---	Yes
1140	Cloudy	2.401e-07	---	---	Yes
1141*	Cloudy	1.837e-07	1.441e-07	6.734e-07	Yes
1141	Cloudy	1.634e-07	---	---	Yes
1224	Cloudy	2.701e-07	---	---	No
1225	Cloudy	---	1.297e-07	1.302e-07	No
1228	Cloudy	9.426e-08	---	---	No
1229	Windy Cloudy	---	1.255e-07	5.060e-07	No
There was rain for 45 minutes from 1245 to 1315.					
1340	Cloudy	---	1.547e-07	2.877e-07	No
1348	Prtly Cloudy	3.130e-07	---	---	No
1349	Cloudy	2.988e-07	---	---	No
Smoke test begins at 114 meters down range.					

TABLE II. TESTS PERFORMED ON 12 SEPTEMBER 1984 (CONT)

Time	Conditions	C _n (LT)	C _n (ST)	C _n (Wan)	Smoke
1405	Cloudy	2.701e-07	---	---	Yes
1406*	Cloudy	2.937e-07	1.063e-07	9.861e-07	Yes
1407	Cloudy	---	3.382e-07	2.237e-07	Yes
1408	Cloudy	2.099e-07	---	---	Yes
1410	Cloudy	2.562e-07	---	---	Yes
1411*	Cloudy	1.542e-07	1.234e-07	4.769e-07	Yes
Telescope out-of-focus since the rain - refocused the telescope on the NPS slit-scan system.					
1414	Cloudy	9.654e-08	---	---	No
1416	Cloudy	9.737e-08	---	---	Yes
1417	Cloudy	9.547e-08	---	---	Yes
1418	Cloudy	9.454e-08	---	---	Yes
1419	Cloudy	9.643e-08	---	---	Yes
1421	Cloudy	1.040e-08	---	---	Yes
1422	Cloudy	9.498e-08	---	---	No
1424	Cloudy	1.060e-07	---	---	Yes
1425	Cloudy	1.077e-07	---	---	No
1427	Cloudy	9.423e-07	---	---	Yes
1428	Cloudy	---	1.334e-07	---	Yes
1429	Cloudy	---	1.367e-07	9.181e-08	Yes
1430	Cloudy	1.605e-07	---	---	Yes
Smoke moved to 800 meters down range.					
1439	Overcast	8.583e-08	---	---	No
1440	Overcast	---	8.431e-08	8.916e-08	No
1447	Overcast	8.950e-08	---	---	No
1448	Overcast	---	9.442e-08	1.745e-07	No
1454	Overcast	---	1.196e-07	1.156e-07	No
1500	Overcast	1.412e-07	---	---	Yes
1500*	Overcast	6.902e-08	4.219e-07	3.306e-07	Yes
1501	Overcast	1.643e-07	---	---	Yes
1502	Overcast	---	1.545e-07	2.931e-07	Yes

TABLE II. TESTS PERFORMED ON 12 SEPTEMBER 1984 (CONT)

Time	Conditions	C _n (LT)	C _n (ST)	C _n (Wan)	Smoke
1504	Overcast	---	1.660e-07	1.397e-07	Yes
1505	Overcast	---	1.807e-07	1.162e-06	Yes
There was some vibration of the platform during last run at 1505.					
1507	Overcast	---	1.712e-07	4.934e-07	Yes
1508	Overcast	---	1.704e-07	2.891e-07	Yes
1510	Overcast	---	1.036e-07	2.733e-07	Yes
1512	Overcast	---	1.050e-07	2.681e-07	Yes
1513	Overcast	---	1.041e-07	1.678e-07	Yes
1515	Thick Smoke	---	1.026e-07	1.847e-07	Yes
1516	Medium Smoke	---	1.048e-07	1.913e-07	Yes
1519	Thin Smoke	---	1.012e-07	1.116e-07	Yes
1520	No Smoke	---	9.361e-08	1.306e-07	No
Moved smoke to 498 meters down range from detectors.					
1529	Overcast	---	1.037e-07	3.272e-07	No
1531	Overcast	---	1.060e-07	1.203e-07	No
1541	Cloudy/Windy	---	1.078e-07	9.332e-07	Yes
1546	Overcast	---	1.048e-07	3.408e-07	Yes
1548	Overcast	---	1.066e-07	4.719e-07	Yes
1553	Overcast	---	1.005e-07	1.953e-06	Yes
1555	Thick Smoke	---	1.072e-07	1.036e-06	Yes
1557	Overcast	---	1.169e-07	2.882e-07	Yes
1559	Overcast	---	1.964e-07	2.059e-07	Yes
1600	Overcast	---	1.060e-07	1.846e-07	Yes
1602	Thick Smoke	---	1.116e-07	1.776e-06	Yes
1603	Medium Smoke	---	1.086e-07	2.307e-07	Yes
1604	Thick Smoke	---	1.146e-07	1.698e-07	Yes
1606	Light Smoke	---	1.034e-07	2.261e-07	Yes
1607	Almost No Smoke	---	1.078e-07	3.023e-07	Yes
1608	Overcast	---	9.577e-08	9.809e-08	No
1610	Almost No Smoke	---	1.094e-07	2.297e-07	Yes
1612	Black Smoke from Rubber	---	1.043e-07	8.193e-07	Yes

TABLE II. TESTS PERFORMED ON 12 SEPTEMBER 1984 (CONT)

Time	Conditions	C _n (LT)	C _n (ST)	C _n (Wan)	Smoke
1613*	Black Smoke	5.908e-07	Negative	2.476e-07	Yes
1614	Med Black Smoke	---	1.721e-07	2.728e-07	Yes
1614*	Some Smoke	9.526e-08	Negative	5.678e-08	Yes
1615	Very Light Black Smoke	---	1.076e-07	8.331e-07	Yes
1617	Almost No Smoke	---	1.138e-07	8.414e-08	Yes
1619	Threatening Rain	---	1.038e-07	1.471e-07	No

The effect of the red phosphorus smoke was small and noticeable only when the sky was overcast and very little turbulence. The change in the C_n^2 was only a 3 to 10 percent increase. The black smoke from the burning rubber caused about 60 percent increase in the C_n^2 . The increase in the C_n^2 is due to the heat of combustion causing the region of the smoke to have a larger temperature variation than the nearby air without smoke. The burning rubber gave off considerably more heat than the smoke grenade, hence, there was much more effect due to the smoke from the rubber than the phosphorus. If it had not been overcast this effect probably would have been hidden by the higher turbulence when the sun was shining.

2.4 VIDEO DATA ANALYSIS

a. The video data obtained in the field was analyzed with the equipment setup shown in figure 2. The video cassette recordings were first dubbed onto an Ampex VPR-80 1-inch reel-to-reel video tape recorder to make use of some of the Ampex recorder's special features, such as the ability to view single video fields. The time base corrector was an Ampex TBC-80, designed to enable the Ampex recorder to perform special video effects. The time base corrector also allowed for adjustment of the video signal levels and for the video black level.

b. Each field of video to be analyzed was digitized into the memory of a Quantex DS-30 video processor. The field of video is stored as 512 x 512 array of picture elements (pixels) represented by a gray scale value between 0 (black) and 255 (white). These values could be randomly accessed and transferred via the Hewlett-Packard interface bus (HPIB) to an HP 1000 minicomputer.

c. Before a processing run was made, a typical field of video was digitized. The digitized values were read into the computer using the program WINDOW, developed by the Electromagnetic Environmental Test Facility (EMETF), which helped locate the position of the laser image in the field. Only data without a 256- by 256-pixel window, centered on the laser image, were subsequently processed. WINDOW also enabled the scaling parameter, SCALE, to be determined. SCALE was determined by first digitizing a field of video acquired

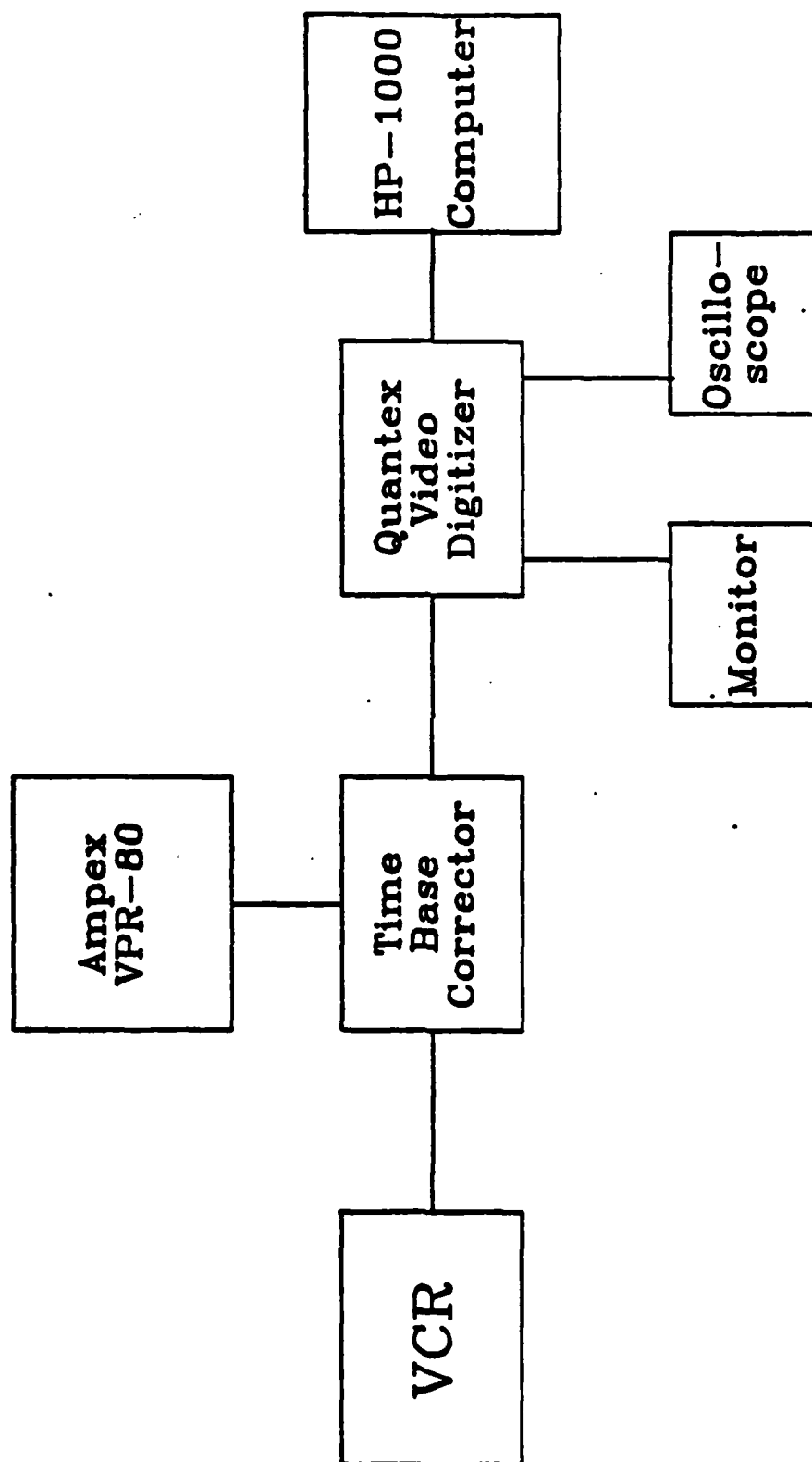


Figure 2. Data analysis setup.

when a diffraction grating was in front of the camera optics. WINDOW was used to count the number of pixels between the central and first maxima of the diffraction pattern. The calculated angular separation in microradians of the maxima was divided by their pixel separation to derive the value of SCALE.

d. The actual processing of the digitized video data was performed by a FORTRAN Program called MTFLTV, which was supplied by NPS. This program has as inputs the digitized video data as well as test parameters such as the distance from the laser to the camera and specifications of the front-end optics. It outputs the optics MTF, the atmospheric MTF, and the turbulence structure, C_n^2 .

2.5 VIDEO DATA RESULTS

a. Data from 12 different time periods on September 12 were processed. The C_n^2 values calculated for long-term, short-term, and wander data are shown separately in table III. This table also indicates the start time of each processing run and its duration in seconds. For each run, 60 separate video fields were processed. These fields were evenly distributed within the run's duration time; so several fields were not processed.

TABLE III. CALCULATED ATMOSPHERIC STRUCTURE PARAMETERS

Run No.	Time	Duration (s)	C_n^2 (Short-Term)	C_n^2 (Long-Term)	C_n^2 (Wander)
1	9:00:00	6	4.862×10^{-14}	8.000×10^{-14}	8.936×10^{-13}
2	9:30:50	12	8.858×10^{-14}	1.188×10^{-13}	7.387×10^{-13}
3	10:00:50	12	8.153×10^{-14}	1.703×10^{-13}	3.328×10^{-12}
4	10:39:00	12	9.747×10^{-14}	1.445×10^{-13}	1.735×10^{-12}
5	11:10:00	12	9.412×10^{-14}	1.221×10^{-13}	1.528×10^{-12}
6	11:30:00	12	5.018×10^{-14}	6.339×10^{-14}	3.008×10^{-13}
7	11:40:48	12	2.077×10^{-14}	3.733×10^{-14}	4.535×10^{-13}
8	14:06:00	12	1.130×10^{-14}	4.148×10^{-14}	9.724×10^{-13}
9	14:11:00	12	1.522×10^{-14}	2.378×10^{-14}	2.274×10^{-13}
10	15:00:00	12	1.780×10^{-15}	4.764×10^{-15}	1.028×10^{-13}
11	16:12:53.30	6	-3.320×10^{-16}	3.490×10^{-15}	6.133×10^{-14}
12	16:13:35	6	-3.711×10^{-16}	9.074×10^{-15}	3.224×10^{-13}

b. The short-term C_n^2 for runs 11 and 12 turned out to be negative, which is, of course, an invalid result. The specific reasons for this result are unclear; however, in both of these runs, the spot size was small and smoke was present in the optical path.

c. It was discovered that the Quantex video digitizer tended to clip high level video signals; therefore, the laser image had an intensity plateau in its center. When this plateau occurred, the processing program produced negative values of C_n^2 for both the short term and long term. The problem was corrected by lowering the video output level from the time base corrector until it was just below the clipping point. It was also discovered that the program produced negative C_n^2 values if the background video level was high. This problem was corrected by adjusting the black level on the time base corrector until all the background was at or below the black video level.

SECTION 3. APPENDICES

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APPENDIX A. VIDEO TEST DATA ACQUISITION FOR ATMOSPHERIC MTF MEASUREMENT

a. This appendix outlines the general procedures for obtaining the video images used as inputs to programs MTFLTV and MTFLD. The procedures discussed here are not complete and do not require strict adherence.

b. The equipment essential to obtaining the images consists of:

- (1) a laser
- (2) a video camera
- (3) a telescopic lens adapted to the camera
- (4) a filter which passes light only at the laser frequency
- (5) a video recorder
- (6) a time annotator
- (7) a video monitor
- (8) an oscilloscope
- (9) a large white target board.

The camera system and the laser system must be free from vibrations.

c. To obtain the images needed by MTFLTV, the laser (e.g., a low-power helium-neon laser) is set up a short distance behind the target board. The camera and its recording equipment are set up at least one kilometer in front of the target board. The camera is aimed at the laser which radiates through a small hole in the center of the board. The camera's field of view is limited to the surface of the target board by the telescopic lens. Thus, the desired image recorded from the camera is a bright spot (the laser beam) in the center of a dark background (the target board). The images are recorded by a video recorder such as a VCR for later processing by MTFLTV.

d. Care must be taken to insure the laser beam does not overdrive the camera's amplifiers, causing the spot image to be clipped. Clipping may be detected by connecting the oscilloscope to the camera video outputs. To reduce the intensity of the beam at the camera, a diverging lens may be placed in front of the laser.

e. Time annotation should be placed on the video so that the results of data processing can be related to the time of day. A log should be kept of the times when measurements are taken and of the current weather conditions.

f. At some point of low atmospheric turbulence, a large diffraction grating should be placed in front of the camera optics and a video recording made of the resulting diffraction pattern. The orientation of the diffraction grating must be parallel to that of the video scan direction. This recording through the grating is necessary to determine the scaling parameter (SCALE)

which is input to MTFLTV. Also, the camera-to-laser distance must be measured to provide the ranging parameter (RANGE). If the telescopic lens is of the Cassegrainian type, then its obscuration ratio (OBS) must be determined by taking the ratio of the diameters of the central obscuration ratio and the whole lens. Finally, the diameter of the lens must be measured to provide the optics diameter (DOPT).

g. Because MTFLD was designed for use with laser designator beams, its equipment setup differs somewhat from that of MTFLTV. Laser designator beams are generated by high-power lasers, which usually cannot be viewed directly through cameras. Thus, for MTFLD, the camera and the laser both face the target board from the same side. The camera is set up close to the board so that the board fills its field of view without the telescopic lens. The laser is set up at least one kilometer away from the board. Recordings are then made of the laser spot that appears on the target board. The rest of the setup and measurements are the same as for MTFLTV.

APPENDIX B - PART 1. HARDWARE AND SOFTWARE SYSTEMS FOR VIDEO
DATA ANALYSIS

1. INTRODUCTION

1.1 Test Background

USAEPG and the Naval Postgraduate School (NPS) have jointly developed a video data technique for making a path-weighted measurement of a modulation transfer function (MTF). (See part 2 of this appendix for a general discussion of MTF calculation theory). The feasibility of the technique has been demonstrated in a laboratory environment by comparing the results from the video system with those from the NPS slit-scanning-telescope system. To validate the laboratory comparison of the two techniques, and to validate the laboratory tests themselves as valid measures of field performance, a joint field test was run in September 1984 at Fort Huachuca, Arizona. This appendix describes hardware and software systems used to analyze the video data taken during the field test.

1.2 Software Considerations

The NPS developed software consisting of three main programs (MTFLTV, MTFLD, and PREDICT) and several subroutine and function modules. The development was not done on the present hardware; however, prior to delivery, the NPS modified the software for use on an Hewlett-Packard (HP) HP-1000 minicomputer. Upon delivery, the modified software had not been tested or verified on an HP-1000. (At the time of the writing of this document, MTFLD and PREDICT remain untested and unverified.) In addition, the software delivered was originally written for a much larger and faster computer, where efficiency was not so important as on the HP-1000; processing which took a few minutes on the original computer sometimes requires over an hour on the HP-1000. Those inefficiencies which could be remedied by additional code modifications are addressed in this document.

1.3 Required Peripherals

a. Two pieces of equipment other than the HP-1000 computer are essential for running MTFLTV and MTFLD. The first is a video digitizer with computer-accessible memory. The second is a video recorder capable of stepping through individual video fields.

b. The video digitizer used as the basis for the present versions of MTFLTV and MTFLD is the Quantex DS-30 Video Processor. An effort has been made to isolate the code relating to the Quantex so that the programs can be easily modified for use with another digitizer. The modules affected are VIDEODATA and DIGITIZE.

c. Any video recorder which can be stepped through individual fields may be used, e.g., an Eigen videodisc unit or an Ampex VPR 80 video tape recorder. The programs currently do not depend on the model of video recorder used because the recorder is assumed to be manually operated and is linked to the digitizer only through a video cable.

1.4 Device Efficiency

a. To increase efficiency, the Quantex DS-30 bypasses the FORTRAN formatter and interfaces the program through EXEC calls (operating system level commands). The EXEC calls are probably the most system-dependent part of the programs and should be kept in mind when transporting the code to other operating environments.

b. The manual operation of the video recorder is very time-consuming for the program user. Ideally, the code should be modified so that the programs control both the video recorder and the digitizer. These modifications would be made in the DINPUT module.

2. GENERAL PROGRAM DESCRIPTION

a. The MTF software contains three main programs: MTFLTV, MTFLD, and PREDICT. MTFLTV and MTFLD are very similar and use many of the same program modules. Both use as main inputs a series of digitized video images which, in combination with other inputs such as scale factors and the distance from the laser to the target, are used to calculate the atmospheric MTF. The MTF is then used to calculate C_n^2 , a measure of the atmospheric turbulence affecting image quality.

b. The major difference between MTFLTV and MTFLD field test methods is MTFLTV uses images of a helium-neon laser beam directed at a camera, whereas MTFLD uses images of the reflection of a laser designator beam off a white target board. Both tests place the laser approximately one kilometer away from the target.

c. The third program, PREDICT, uses a previously calculated value of C_n^2 to reconstruct the atmospheric MTF. PREDICT then uses the atmospheric, source, and optics MTF's to predict the image quality of a given optical system.

d. Figures 1-3 show the logical interconnections between the modules in MTFLTV, MTFLD, and PREDICT. Details of the separate modules, including their functions, inputs/outputs, and source code listings, are discussed in appendix C. The programs are structured vertically, i.e. most of the modules have a direct connection only with the main routine and not with each other. Thus, the program flow is fairly simple and straightforward. However, many of the modules do interface through common data blocks, and this fact must be kept in mind when program modifications are made.

e. For MTFLTV and MTFLD, all the input data is provided in modules GINPUT and DINPUT. GINPUT allows for the input of test-specific parameters via an interactive terminal or a data file. DINPUT preprocesses the digitized video data and stores the results in arrays. The data in these arrays is then processed further by other modules in MTFLTV and MTFLD. Each time the data is processed, the new results overwrite the previous data. Intermediate results may be output to data files using the OUTPUT module. The ultimate values, the C_n^2 parameters, are displayed on the operator's terminal as well as being output to a data file.

(Text continued on page B-6)

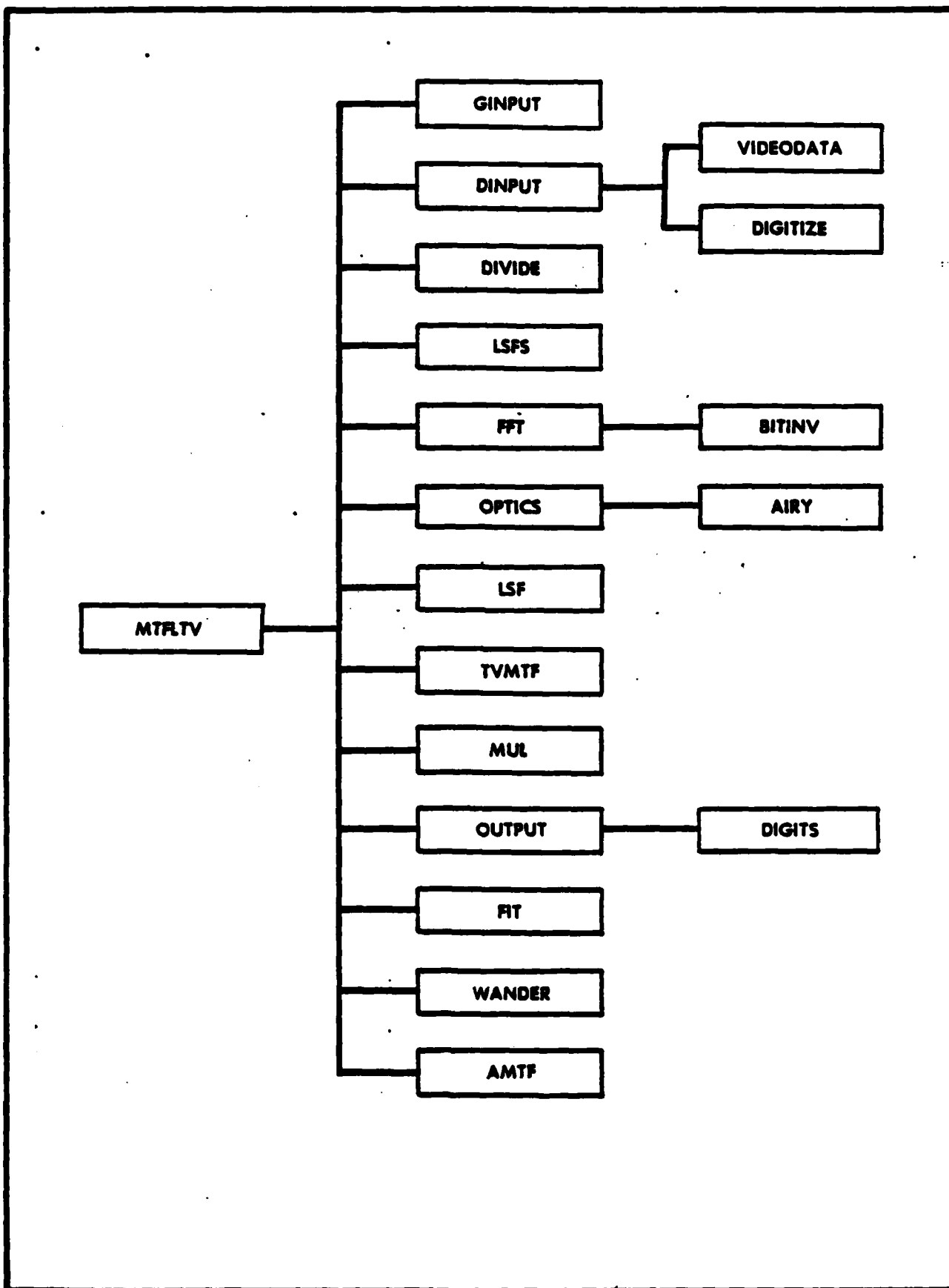


Figure 1. MFLTV Module Interconnections

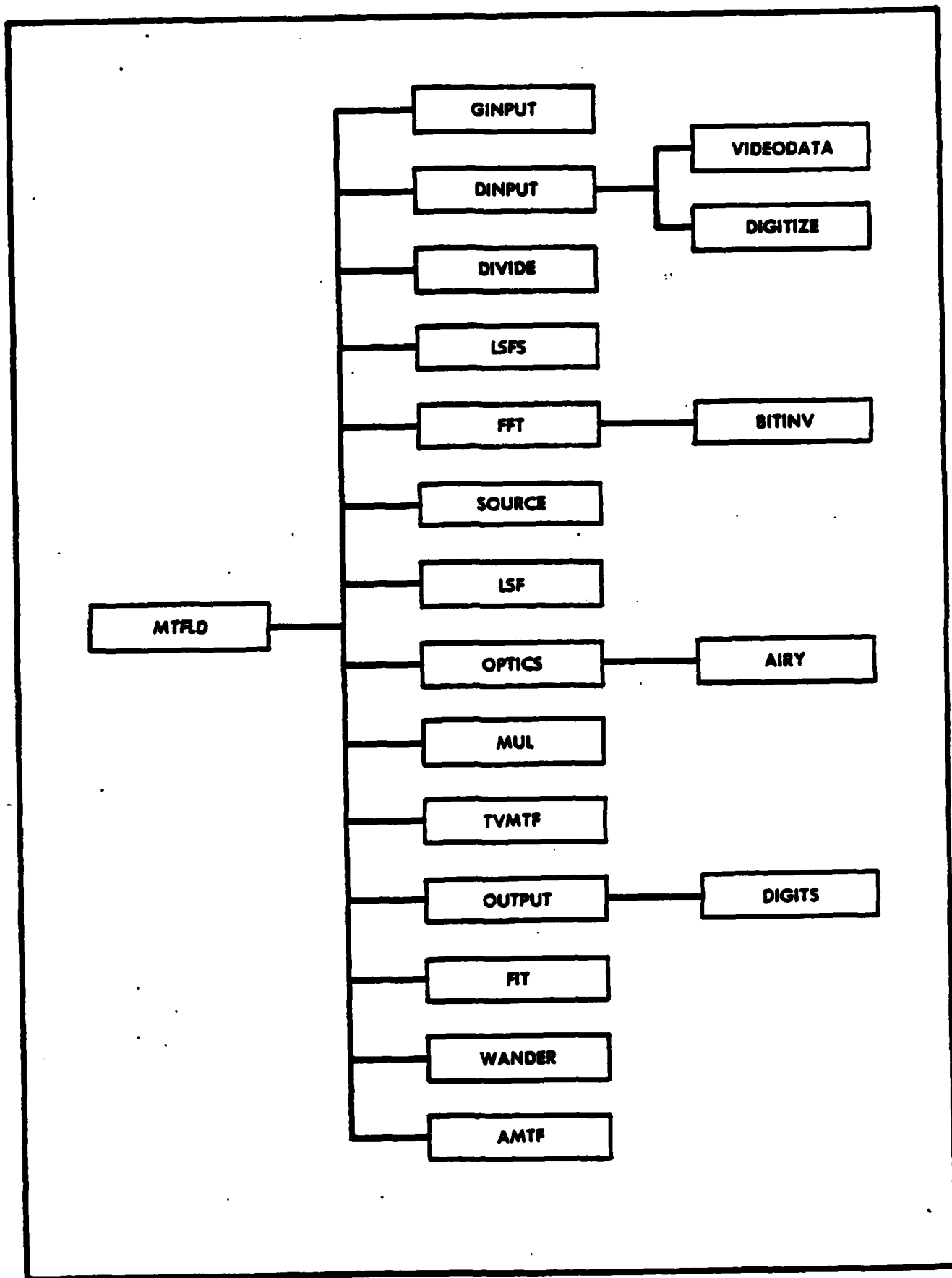


Figure 2. MTFLD Module Interconnections

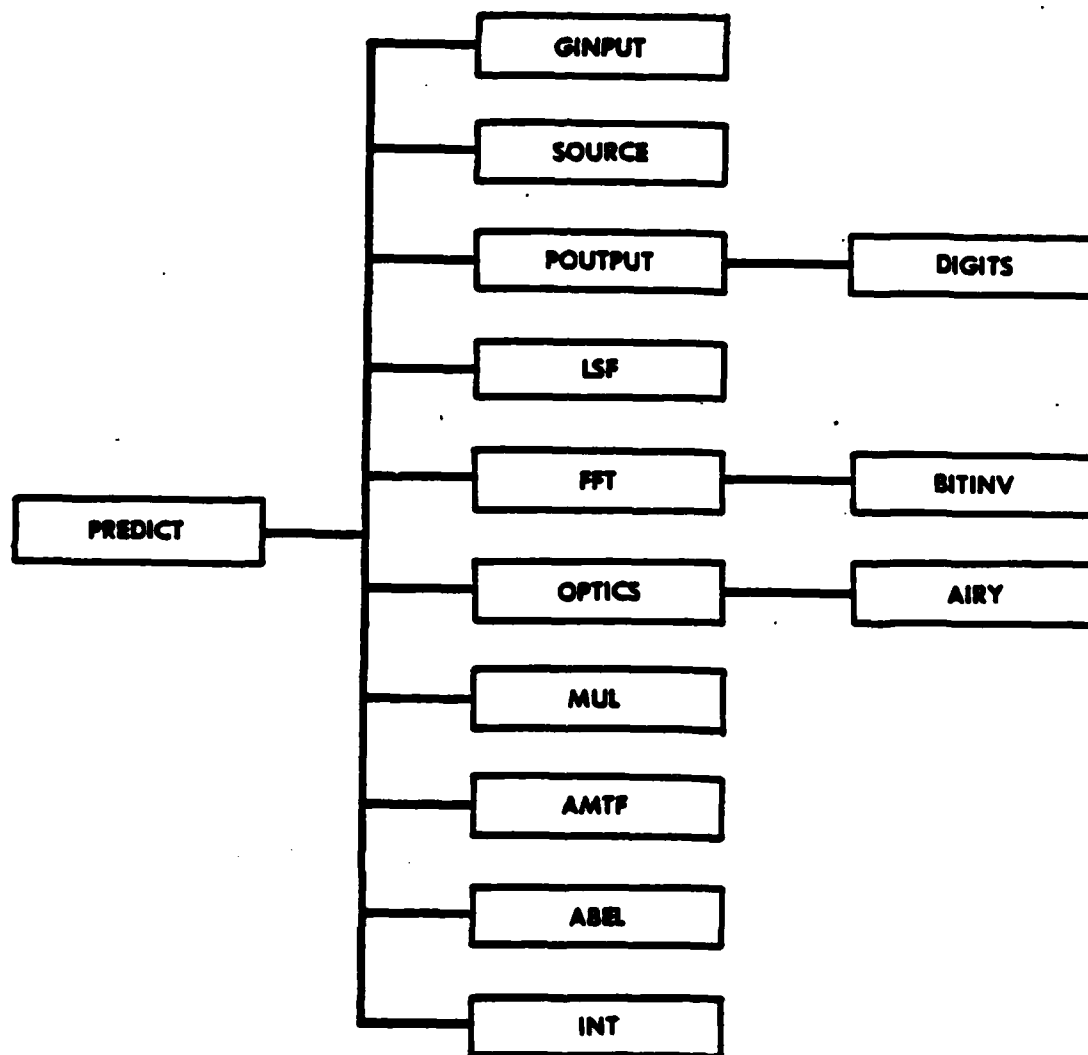


Figure 3. PREDICT Module Interconnections

f. For PREDICT, the module GINPUT performs all of the input. Again, many of the intermediate calculations as well as the final results may be output to data files. This output is performed by the POUTPUT module.

3. RUNNING THE PROGRAMS

3.1 Hardware

a. The programs can be run on HP-1000 series computers under the RTE-6/VM operating system. They have also been run on the HP A-600 computer, under the RTE-A operating system. All program modules are coded in HP's FORTRAN 7X. The programs currently require that a Quantex DS-30 Video Processor be linked to the computer via the HP Interface Bus (HPIB).

b. The programs MTFLTV and MTFLD are especially large and barely fit into a 64 kilobyte memory partition. When modifications are made to the program, it may be necessary to use a larger partition, reduce the sizes of the arrays, or put the arrays into the Extended Memory Areas (EMA).

3.2 Program Inputs

The general input parameters which enter a program via module GINPUT may be input interactively at the operator's terminal or from the file INPUT.DAT. In either case, these parameters must be determined by the operator prior to running a program. Below is a brief description of each input parameter and how its value is determined. [NOTE: LTV denotes use in MTFLTV; LD in MTFLD; P in PREDICT.]

(1) A (real). The maximum intensity of the laser source in watts/steradian. (P)

(2) DATE (character*80). Time and date of the run; placed in the header of the output files. (LTV, LD)

(3) DOPT (real). The diameter of the objective of the optics in meters; determined by measuring across the objective. (LTV, LD, P)

(4) EXT (real). The extinction coefficient of the atmosphere in meters⁻¹. (P).

(5) HEADER1 (character*80). Comments about the run; placed in the header of the output files (LTV, LD). Information about the laser source. (P)

(6) HEADER2 (character*80). Comments about the weather; placed in the header of the output files (LTV, LD). Information about the optics. (P)

(7) IO (integer). Parameter specifying whether or not all intermediate calculations are to be output. If 0, then no output occurs; if 1, then all intermediate calculations are to be output. (LTV, LD, P)

(8) LOPTICS (integer). Parameter specifying the type of optics diffraction function to be used by the program. If 1, then the function is computed; if 2, it is input from a file. (P)

(9) LSOURCE (integer). Parameter specifying the type of laser source function to be used by the program. If 1, then a Gaussian source function is computed; if 2, then the source function is input from a file; if 3, then the source-optics function combination is input from a file. (P)

(10) NFLDS (integer). The number of fields of video data to be processed. Note that the fields may be separated by any fixed time interval. (LTV, LD)

(11) OBS (real). The ratio of the diameter of the central obscuration of the objective to the diameter of the objective; determined by measuring across the obscuration and dividing by DOPT. (LTV, LD, P)

(12) RANGE (real). The distance between the optics and the target; determined by a surveyor's range finder. (LTV, LD, P)

(13) SCALE (real). Angular scale of a digitized video image as specified by the angle subtended by one pixel; in microradians per pixel. Determined by digitizing a video field acquired through a diffraction grating, calculating the angular separation of the central and first maxima of the laser image diffraction pattern (a function of the diffraction grating), counting the number of pixels between these maxima in the digitized image, and finally taking the ratio of the calculated angular separation of the maxima and the number of pixels between the maxima. (LTV, LD, P)

(14) SQCN (real). The previously-determined value of C_n^2 for the atmosphere in units of meters^{-2/3}. (P)

(15) SSIGMA (real). The divergence of the laser source, i.e. the angle between the beam center and the line at which the laser's energy falls to 1/e of its peak energy; in radians. This value is a characteristic of the laser used; usually determined in the laboratory. (LD, P)

(16) WAV (real). Wavelength of the laser in micrometers; determined by the type of laser used, e.g., a helium/neon laser radiates at 0.6328 μ m. (LTV, LD, P)

(17) XW1, XW2, YW2, YW1 (integer). The left, right, top, and bottom locations of the digitized video window, which is centered on the laser spot image. These locations are specified in pixel units of the digitizer. Care must be taken to insure that the window is large enough to completely enclose the laser spot images; however, making it unnecessarily large significantly increases processing time. Currently, the top and bottom of the window must be separated by either 256 or 512 pixels. (LTV, LD)

3.3 Compiling and Linking the Programs

a. The programs MTFLTV, MTFLD, and PREDICT consist of several modules, each of which exists in a separate file. A command file has been created which automatically compiles and links all of these modules. The file, named COMP&LINK.CMD, is listed in appendix D. To utilize the file, one simply enters "TR COMP&LINK.CMD" at a terminal, and all of the command lines in the file are executed sequentially.

b. COMP&LINK.CMD does the following:

- (1) The operator must verify that the list of source code file names in MERGE.CMD is up-to-date
- (2) All source code files (format: NAME.FTN) listed in MERGE.CMD are compiled
- (3) The extensions of the compiled versions are changed to .REL (for "relocatable")
- (4) MERGE concatenates all .REL files into one file, MTF.REL
- (5) LINDX creates MTF.LIB, an indexed version of MTF.REL
- (6) To save disk space, all .REL files are purged
- (7) LINK links MTFLTV, MTFD, and PREDICT into the system.

c. Control is then returned to the operator. The programs are ready to be run. Note that MTF.LIB is not purged and may be accessed to link with other programs using MTF modules.

3.4 MTFLTV Run Procedure

At present MTFLTV and MTFD require a significant amount of operator effort to run successfully. The following set of step-by-step procedures is presented to help the operator properly setup and run MTFLTV and MTFD.

- (1) Set up the processing equipment as shown in figure 4. Note that all connections are made using 75 Ω video cable except the connection to the computer, which uses an HPB cable.
- (2) Make sure that the logical unit numbers of the HPB card and video digitizer correspond to those in variable LUHPB and LUDS30 of modules VIDEODATA and DIGITIZE. If they do not, then change the values of LUHPB and LUDS30. Programs MTFLTV and MTFD must then be recompiled and relinked.
- (3) Make sure that the program is ready to run on the system (see para 3.3).
- (4) Set the working directory to /MTF/.
- (5) Make sure that there is enough room in directory /MTF/ to store all the program output if the output is to be stored. If data from previous runs is to be saved, make sure the data files have been renamed.
- (6) With the stop-field video recorder (in this case, an Ampex VPR-80), locate the start field of the video data to be processed. For the time interval over which the video data is to be processed, visually check the picture for gross problems, such as picture break-up, which might affect the results. If the video signal is bad, then the data may not be reducible. Also, monitor

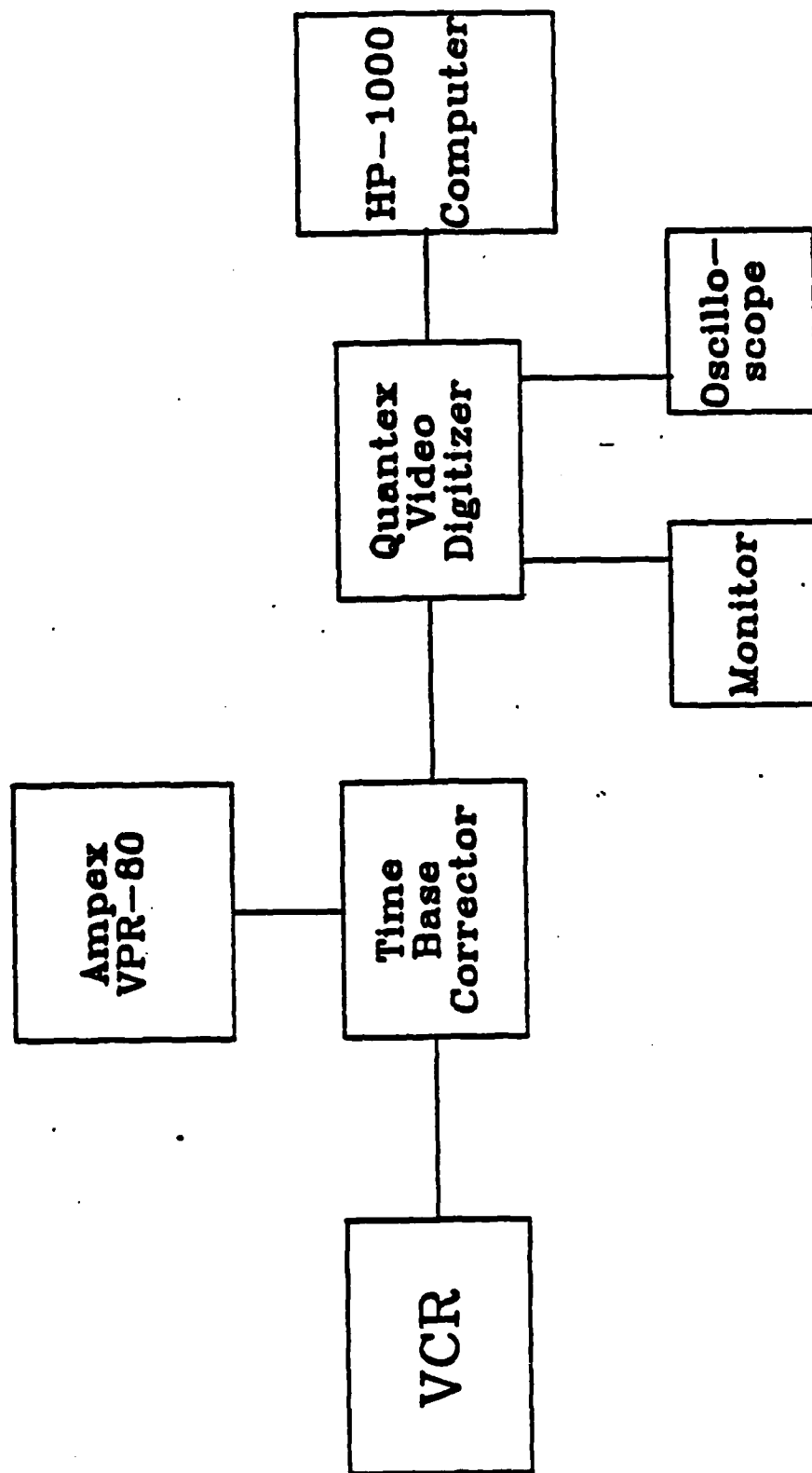


Figure 4. Processing Equipment Setup.

the oscilloscope for any signs of signal clipping, which causes the spot intensity profile on the oscilloscope to have a plateau. Clipping can usually be alleviated by lowering the video signal level out of the time base corrector. If the signal is clipped on the recording, then that video data is not reducible.

(7) Digitize one field of video with the video digitizer. Make sure that the digitized video appears the same as the original video and has not been amplified or attenuated in any way.

(8) Determine the values of the general input parameters for the program (see para 3.2). If these are to be input from a data file by the program, then enter the values into file INPUT.DAT.

(9) Again, locate the start field of the video data to be processed.

(10) Run the program.

(11) The program asks if the general input parameters are to be entered at the operator's terminal. Entering "1" at the terminal initiates the interactive input routine. Entering any other number causes the parameters to be read from the input file. The interactive input routine asks the operator to enter the parameters one-by-one at the terminal.

(12) Once all of the general input parameters are entered, the program sounds the beep on the operator's terminal and displays the message:

"Advance to field #1 out of [NFLDS],"

where [NFLDS] is the number of fields of video to be processed. Be sure the stop-field recorder is displaying the correct field. Once it is, enter "1" at the terminal. The program inputs the video data from the digitizer and preprocesses it. At this point the program is operating in module DINPUT. Once the current video field is preprocessed, the program loops back to the message which tells the operator to advance to the next field. This loop continues until all the fields have been digitized and the data preprocessed. Note that it is not necessary to process every field of video in the time interval of interest. However, the time separation between fields must remain fixed. For example, suppose ten seconds of video data is to be processed. This ten seconds contains 600 fields. If the operator wants to only process 60 fields in total, then every tenth field should be processed.

(13) After the video data has been digitized and preprocessed, the program processes the data further without operator intervention. The values of the long term, short term, and wander C_n^2 are output both to the terminal and to the file OUTPUTCN.DAT. If the full output option was chosen (IO set to one), then the intermediate calculations of the PSF, LSF, atmospheric MTF, etc., are output to files OUTPUT[nn].DAT, where [nn] is a different number for each type of output.

(14) The program terminates. Each run's output files must be renamed if they are to be protected from overwriting.

3.5 PREDICT Run Procedure

The procedures for running PREDICT are straightforward.

- (1) Make sure the program is ready to run on the system (see para 3.3).
- (2) Set the working directory to /MTF/.
- (3) Make sure that directory /MTF/ has enough room to store the program outputs. If previous data is to be saved, make sure the data files have been renamed so it is not overwritten.
- (4) Determine the values of the general input parameters for the program (see para 4.2). If these are to be input from a data file by the program, then enter the values into file INPUT.DAT.
- (5) Run the program.
- (6) The program asks if the general input parameters are to be entered at the operator's terminal. Entering "1" at the terminal initiates the interactive input routine. Entering any other number causes the parameters to be read from the input file. The interactive input routine asks the operator to enter the parameters one-by-one at the terminal.
- (7) The program then runs without further operator intervention. The program outputs are written into files OUTPUT[nn].DAT, where [nn] is a different number for each type of output.
- (8) The program terminates. Each run's output files must be renamed if they are to be protected from overwriting.

APPENDIX B, PART 2. THEORY OF MTF CALCULATIONS

a. This appendix presents some of the background theory behind the calculations performed by the subject programs. This discussion is not meant to be rigorous; rather, the reader is advised to consult the references listed in appendix E for more complete expositions.

b. Anything which lies between object (source) and image (response) affects the image quality of an optical system. Optical systems themselves degrade images from light sources due to effects such as diffraction and aberrations. The planar description of this image degradation is the point spread function (PSF). The one-dimensional (single variable) analog of the PSF is the line spread function (LSF), the measure of an optical system's response to a slit source of light. The LSF can be generated from the PSF by integrating over one of the two dimensions of a point source image. The MTF is the real part of the Fourier transform of the PSF or of the LSF. MTF's are often used when analyzing image quality, rather than PSF's or LSF's, because the overall MTF (and thus the image quality) of a complex optical system can be simply determined by multiplying the MTF's of each component of the system.

c. An MTF can be determined for any source of image degradation which can be isolated, including lenses, cameras, imaging sensors, and the atmosphere. The image degradations caused by the atmosphere are a function of density fluctuations, and can be described by the index of refraction structure parameter, C_n^2 . C_n^2 may be determined statistically by relating distance to the fluctuation amplitude of the index of refraction. Alternatively, C_n^2 may be approximated using Fried's formula by performing a least squares fit of the measured atmospheric MTF:

$$MTF(x) = Ae^{-C_n^2 x^2}$$

The second method is used by MTFLTV and MTFLD. On the other hand, PREDICT uses Fried's formulas and a value of C_n^2 (either from the programs above or from manual input) to calculate the atmospheric MTF.

APPENDIX C. MODULE DESCRIPTIONS AND SAMPLE DATA PRINTOUTS FOR THE
MTF ANALYSIS COMPUTER PROGRAM

Part 1 of this appendix comprises module information sheets, each containing a brief description of a module, a list of which modules reference it, a list a data interfaces with other modules, and notes which a programmer might find useful when maintaining and modifying the code. Note that the following compiler instructions are specific to present compiler: "FTN7X,L,Q" at the beginning of each module listing, and "FILES(0,2)" in the main program listings.

Part 2 of this appendix contains sample data printouts for a representative run (#3) processed by the program MTFLTV. The following sets of data are included:

1. Long-term raw data
2. Short-term raw data
3. Long-term LSFT adjusted data
4. Short-term LSFT adjusted data
5. FFT of long-term data
6. FFT of short-term data
7. Long-term MTF of atmosphere
8. Short-term MTF of atmosphere
9. Wander
10. Long-term MTF of atmosphere calculated from FIT
11. Short-term MTF of atmosphere calculated from FIT

In addition, the following sample data sets are included:

1. Optics diffraction pattern
2. LSF of optics diffraction
3. MTF of optics
4. MTF of TV
5. Typical input data

APPENDIX C, PART 1. MODULE DESCRIPTIONS

ABEL

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL ABEL (NPTS, FN)

FUNCTION: Converts a line spread function into a point spread function

REFERENCED BY: PREDICT

INTERFACES: External References: ABS, FLOAT, SQRT

Common Data: None

Formal Arguments:

- (1) NPTS (integer). number of points in array FN to be processed
- (2) FN (real array of size NPTS). items in the array are functional values; on input, FN is the LSF; on output, it is the PSF

Inputs: NPTS, FN

Outputs: FN

AIRY

MODULE TYPE: FORTRAN 7X REAL function subprogram

USAGE: Y = AIRY(X)

FUNCTION: Calculates the value of the Airy function of X.
AIRY(X) = $2 * J_1(X)/X$, where J_1 is the Bessel function of order one.

REFERENCED BY: OPTICS

INTERFACES: External References: ABS, FLOAT, MAX1

Common Data: None

Formal Arguments:

X (real). value of the independent variable of the Airy function

Inputs: X

Outputs: AIRY

AMTF

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL AMTF (LTERM, SQCN, EX, NPTS, MTF)

FUNCTION: Calculates the atmospheric MTF from given values of C_n^2 , range, wavelength, atmospheric extinction, and for short term data, the optics diameter.

REFERENCED BY: MTFLTV, MTFLD, PREDICT

INTERFACES: External References: COS, EXP

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) LTERM (integer). if set to zero on input, then the long term atmospheric MTF is calculated; if set to one, then the short term calculation.
- (2) SQCN (real). the value of C_n^2
- (3) EX (real). the atmospheric extinction factor
- (4) NPTS (integer). the number of elements in array FN
- (5) MTF (real array of size NPTS). the calculated atmospheric MTF

Inputs: LTERM, SQCN, EX, NPTS, WAV, DOPT, SCALE, RANGE

Outputs: EX, MTF

BITINV

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL BITINV (K, L, M)

FUNCTION: Finds the bit inverse of an integer, i.e., its base 2 mirror image, of a given bit length.

REFERENCED BY: FFT

INTERFACES: External References: BTEST, IBSET

Common Data: None

Formal Arguments:

- (1) K (integer). the integer whose bit inverse is to be found
- (2) L (integer). the bit inverse of K
- (3) M (integer). the number of bits in the integers K and L

Inputs: K, M

Outputs: L

DIGITIZE

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL DIGITIZE

FUNCTION: Digitizes one frame of video data using the Quantex DS-30 Video Processor. Control is via the HPPIB.

REFERENCED BY: DINPUT

INTERFACES: External References: EXEC

Common Data: None

Formal Arguments: None

Inputs: None

Outputs: None

NOTE: Currently the logical unit number of the Quantex DS-30 (LU30) is set to 24 and that of the HPPIB controller card (LUHPPIB) is set to 20. These should be set for the particular system configuration in use.

DIGITS

MODULE TYPE: FORTRAN 7X CHARACTER*16 function subprogram

USAGE: CHAR = DIGITS (N, BASE)

FUNCTION: Converts an integer to a character string of digits which represents the integer in a given base.

REFERENCED BY: OUTPUT

INTERFACES: External References: IABS, MOD

Common Data: None

Formal Arguments:

- (1) N (integer). the integer to be converted
- (2) BASE (integer). the number base in which the input integer is to be represented

Inputs: N, BASE

Outputs: DIGITS

DINPUT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL DINPUT (NPTS, DLTA, DSTA, DWD)

FUNCTION: Obtains digitized video data, calculates the long and short term average data, and determines the wander.

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: DIGITIZE, VIDEODATA, FLOAT

Common Data: /WINDOW/ XW1, XW2, YW1, YW2, NFLDS;
/PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT,
A, SSIGMA

Formal Arguments:

- (1) NPTS (integer). number of points in arrays DLTA, DSTA, DLTII, DSTII
- (2) DLTA (real array of size NPTS). long term average of the LSF
- (3) DSTA (real array of size NPTS). short term average of the LSF
- (4) DWD (real array of size NFLDS). wander of the center of the LSF

Inputs: NPTS, NFLDS, XW1, XW2, YW1, YW2, SCALE

Outputs: DLTA, DSTA, DWD

DIVIDE

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL DIVIDE (NPTS, ARRAY1, ARRAY2)

FUNCTION: Divides each element of first array (ARRAY1) by the corresponding element of the second array (ARRAY2). If a divisor is zero, then the quotient is set to zero.

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: None

Common Data: None

Formal Arguments:

- (1) NPTS (integer). number of elements in ARRAY1 and ARRAY2
- (2) ARRAY1 (real array of size NPTS). dividend
- (3) ARRAY2 (real array of size NPTS). divisor

Inputs: NPTS

Outputs: ARRAY1, ARRAY2

FFT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL FFT (LINV, NPTS, FN)

FUNCTION: Calculates the Fourier transform (or inverse Fourier transform) of a real-valued symmetric function using the Fast Fourier Transform (FFT) algorithm. The number of functional values must be an integral power of two.

REFERENCED BY: MTFLTV, MTFDLD, PREDICT

INTERFACES: External References: BITINV, CEXP, CMPLX, CONJG, FLOAT

Common Data: None

Formal Arguments:

- (1) LINV (integer). specifies whether forward (LINV=0) or inverse (LINV=1) Fourier transform is to be calculated.
- (2) NPTS (integer). on input, NPTS is the number of elements in array FN; on output, it is the largest non-zero term of FN
- (3) FN (real array of size NPTS). on input, FN is an array of functional values; on output, it is the forward (or inverse) Fourier transform of these functional values.

Inputs: LINV, NPTS, FN

Outputs: NPTS, FN

NOTE: Complex arithmetic is used in this routine.

FIT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL FIT (CNSQ, COEFF, NPTS, MTF)

FUNCTION: Performs a least squares fit of the measured MTF data to Fried's model of the atmospheric MTF. This operation determines the C_n^2 parameter for the atmosphere.

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: ALOG, EXP, FLOAT

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) CNSQ (real). C_n^2 , the atmospheric turbulence structure parameter
- (2) COEFF (real). the coefficient factor in the MTF formula
- (3) NPTS (integer). number of points in the MTF array
- (4) MTF (real array of size NPTS). MTF functional values

Inputs: NPTS, MTF, WAV, DOPT, SCALE, RANGE

Outputs: CNSQ, COEFF

GINPUT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL GINPUT (LPROG, IO)

FUNCTION: Obtains general parameter inputs for programs MTFLTV, MTFLD, and PREDICT. The parameters may be input interactively or via data file.

REFERENCED BY: MTFLTV, MTFLD, PREDICT

INTERFACES: External References: None

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA
/WINDOW/ XW1, XW2, YW1, YW2, NFLDS
/HEADER/ HEADER1, HEADER2, DATE
/PPARMS/ LSOURCE, LOPTICS, SQCN

Formal Arguments:

- (1) LPROG (integer). parameter specifying which program is being run. If 1, then MTFLTV is being run; if 2, then MTFLD; if 3, then PREDICT.
- (2) IO (integer). parameter specifying whether or not all data is to be output to files. If 0, then data is not output; if 1, then it is.

Inputs: LPROG

Outputs: IO, WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA, XW1, XW2, YW1, YW2, NFLDS, HEADER1, HEADER2, DATE, LSOURCE, LOPTICS, SQCN

INT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL INT (LNORM, NPTS, FN)

FUNCTION: Integrates the point spread function to find the power inside a circle as a function of radius. Will return the power function normalized to total power if LNORM = 1.

REFERENCED BY: PREDICT

INTERFACES: External References: FLOAT

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) LNORM (integer). if 0, returns unnormalized power function;
if 1, returns normalized power function
- (2) NPTS (integer). number of points in array FN
- (3) FN (real array of size NPTS). items in the array are functional values; on input FN is the PSF; on output it is the power integral of the PSF as a function of radius

Inputs: LNORM, NPTS, FN, SCALE, RANGE

Outputs: FN

LSF

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL LSF (NPTS, FN)

FUNCTION: Converts a radially symmetric point spread function into a line spread function

REFERENCED BY: MTFLTV, MTFLD, PREDICT

INTERFACES: External References: FLOAT, IFIX, SQRT

Common Data: None

Formal Arguments:

- (1) NPTS (integer). number of points in the array FN
- (2) FN (real array of size NPTS). items of the array are functional values; on input, FN is the PSF; on output, it is the LSF

Inputs: NPTS, FN

Outputs: FN

LSFS

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL LSFS (NPTS, FN)

FUNCTION: Shifts a line spread function so that it is centered at the origin

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: None

Common Data: None

Formal Arguments:

- (1) NPTS (integer). number of points in array FN
- (2) FN (real array of size NPTS). items in the array are functional values; on input, FN is the non-centered LSF; on output, it is the centered LSF

Inputs: NPTS, FN

Outputs: FN

MUL

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL MUL (NPTS, ARRAY1, ARRAY2)

FUNCTION: Performs an element by element multiplication of ARRAY1 by
 ARRAY2 and returns the result in ARRAY1

REFERENCED BY: MTFLTV, MTFLD, PREDICT

INTERFACES: External References: None

Common Data: None

Formal Arguments:

- (1) NPTS (integer). number of elements in ARRAY1
 and ARRAY2
- (2) ARRAY1 (real array of size NPTS). on input, ARRAY1
 is the first factor array; on output, it is the
 resultant product array
- (3) ARRAY2 (real array of size NPTS). the second
 factor array

Inputs: NPTS, ARRAY1, ARRAY2

Outputs: ARRAY1

OPTICS

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL OPTICS (NPTS, FN)

FUNCTION: Calculates the point spread function (diffraction pattern) of the telescope optics

REFERENCED BY: MTFLTV, MTFLD, PREDICT

INTERFACES: External References: AIRY, FLOAT

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) NPTS (integer). number of points in array FN
- (2) FN (real array of size NPTS). items in the array are functional values; the computed optics PSF

Inputs: NPTS, DOPT, OBS, SCALE, WAV

Outputs: FN

OUTPUT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL OUTPUT (LHEAD, NPTS, ARRAY)

FUNCTION: Outputs calculations of the PSF, LSF, MTF, etc. to data files.

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: DIGITS

Common Data: /HEADER/ HEADER1, HEADER2, DATE

Formal Arguments:

- (1) LHEAD (integer). parameter specifying which title is to be printed at top of the data file
- (2) NPTS (integer). the number of elements in array ARRAY
- (3) ARRAY (real array of size NPTS). array of values which are to be output to the data file

Inputs: LHEAD, NPTS, ARRAY, HEADER1, HEADER2, DATE

Outputs: None

POUTPUT

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL POUTPUT (LHEAD, NPTS, ARRAY)

FUNCTION: Outputs calculations of the PSF, LSF, MTF, etc. to data files.

REFERENCED BY: PREDICT

INTERFACES: External References: DIGITS

Common Data: /HEADER/ HEADER1, HEADER2, DATE

Formal Arguments:

- (1) LHEAD (integer). parameter specifying which title is to be printed at top of the data file
- (2) NPTS (integer). the number of elements in array ARRAY
- (3) ARRAY (real array of size NPTS). array of values which are to be output to the data file

Inputs: LHEAD, NPTS, ARRAY, HEADER1, HEADER2

Outputs: None

SOURCE

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL SOURCE (NPTS, FN)

FUNCTION: Calculates the values of a Gaussian source distribution function

REFERENCED BY: MTFLD

INTERFACES: External References: EXP, FLOAT

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) NPTS (integer). number of points in array FN
- (2) FN (real array of size NPTS). items in the array are functional values; the computed Gaussian source distribution function

Inputs: NPTS, A, SCALE, SSIGMA

Outputs: NPTS, FN

TVMTF

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL TVMTF (NPTS, FN)

FUNCTION: Obtains the modulation transfer function of the TV system

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: None

Common Data: None

Formal Arguments:

 (1) NPTS (integer). number of elements in array FN

 (2) FN (real array of size NPTS). items in the array
 are functional values; the TV system MTF

Inputs: NPTS

Outputs: FN

NOTE: Currently, this module calculates a simple step function
 for the TV system MTF. It would have to be modified to
 allow for a more complicated MTF.

VEODATA

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL VEODATA (ROW, ROWSUM)

FUNCTION: Finds the sum of pixel values along a given row. The row must lie between the top and bottom window limits, YW2 and YW1, and the length of the row is determined by the left and right window limits, XW1 and XW2.

REFERENCED BY: DINPUT

INTERFACES: External References: ABRT, EXEC, IAND, ISHFT

Common Data: /WINDOW/ XW1, XW2, YW1, YW2, NFLDS

Formal Arguments:

- (1) ROW (integer). the digitized video field row which is to be summed
- (2) ROWSUM (real). the sum of pixel values along the row of pixels given by ROW

Inputs: ROW, XW1, XW2, YW1, YW2

Outputs: ROWSUM

NOTE: Currently the logical unit number of the Quantex DS-30 (LUDS30) is set to 24 and that of the HPPIB controller card (LUHPIB) is set to 20. These should be set for the particular system configuration in use.

WANDER

MODULE TYPE: FORTRAN 7X subroutine

USAGE: CALL WANDER (CNSQ, NPTS, FN)

FUNCTION: Calculates the value of C_n^2 from the wander of the laser spot image

REFERENCED BY: MTFLTV, MTFLD

INTERFACES: External References: FLOAT

Common Data: /PARAMS/ WAV, DOPT, OBS, SCALE, RANGE, EXT, A, SSIGMA

Formal Arguments:

- (1) CNSQ (real). value of C_n^2 , calculated from wander data
- (2) NPTS (integer). number of elements in array FN
- (4) FN (real array of size NPTS). items in the array are functional values; locations of the laser spot-image center as a function of time

Inputs: NPTS, FN, DOPT, RANGE, SCALE

Outputs: CNSQ

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APPENDIX C, PART 2. SAMPLE DATA PRINTOUTS

RUN 3

LONG TERM RAW DATA

[illegible]

RUN 3

SHORT TERM RAW DATA

[illegible]

RUN 3

FFT OF SHORT TERM

107520.70	107411.22	107083.37	106538.97	105780.97	104813.47	103641.73	102271.97
100711.59	98968.891	97053.109	94974.359	92743.453	90371.844	87871.531	85254.922
82534.844	79724.375	76836.797	73885.625	70884.359	67846.344	64784.711	61712.242
58641.414	55584.094	52551.812	49555.508	46605.586	43711.781	40883.078	38127.859
35453.070	32865.641	30371.168	27974.574	25680.047	23490.980	21410.020	19438.902
17578.723	15829.682	14191.365	12662.740	11242.244	9927.834	8716.969	7606.731
6593.698	5674.041	4843.556	4097.937	3432.622	2842.980	2324.379	1872.094
1481.447	1147.648	865.982	631.732	440.422	287.711	169.612	82.094
21.257	-16.002	-33.231	-33.596	-20.051	4.760	38.512	79.110
124.786	173.864	224.868	276.438	327.372	376.678	423.570	467.492
508.070	545.021	578.106	607.191	632.140	652.917	669.591	682.338
691.490	697.330	700.191	700.310	697.906	693.175	686.324	677.714
667.524	656.296	644.322	631.871	619.141	606.250	593.309	580.431
567.793	555.567	543.955	533.059	522.907	513.455	504.634	496.387
488.725	481.710	475.366	469.770	464.859	460.521	456.569	452.865
449.303	445.821	442.420	439.146	436.070	432.935	429.668	426.089
422.228	418.040	413.522	408.707	403.637	398.286	392.588	386.435
379.750	372.503	364.769	356.659	348.284	339.700	330.943	321.962
312.724	303.183	293.364	283.384	273.361	263.383	253.521	243.751
234.076	224.434	214.873	205.452	196.288	187.474	179.052	171.046
163.291	155.788	148.460	141.307	134.389	127.795	121.588	115.775
110.316	105.118	100.101	95.224	90.494	85.952	81.642	77.590
73.758	70.063	66.414	62.779	59.152	55.584	52.157	48.926
45.881	42.977	40.124	37.234	34.287	31.302	28.379	25.573
22.866	20.398	18.083	15.867	13.715	11.651	9.735	8.045
6.648	5.551	4.726	4.104	3.641	3.308	3.161	3.290
3.774	4.659	5.927	7.523	9.353	11.352	13.507	15.845
18.435	21.315	24.504	27.951	31.599	35.369	39.236	43.240
47.365	51.724	56.308	61.058	65.901	70.718	75.445	80.056
84.582	89.095	93.632	98.187	102.707	107.110	111.280	115.198
118.834	122.239	125.423	128.436	131.238	133.756	135.925	137.704
139.172	140.145	141.033	141.527	141.967	141.993	141.765	141.215
140.066	138.633	136.893	134.936	132.827	130.594	128.197	125.611
122.826	119.882	116.828	113.773	110.792	107.900	105.077	102.317
99.606	96.940	94.386	92.051	90.015	88.340	87.002	85.953
85.130	84.468	83.970	83.652	83.581	83.769	84.219	84.892
85.683	86.563	87.476	88.407	89.400	90.449	91.538	92.603
93.560	94.299	94.760	94.923	94.814	94.474	93.928	93.179
92.178	90.852	89.141	87.021	84.513	81.660	78.519	75.131
71.515	67.662	63.565	59.235	54.737	50.164	45.613	41.146
36.779	32.574	28.480	24.487	20.621	16.936	13.511	10.423
7.746	5.483	3.617	2.111	.933	.080	-.441	-.594
-.380	.182	1.029	2.099	3.330	4.682	6.149	7.738
9.471	11.313	13.225	15.097	16.848	18.401	19.703	20.772
21.578	22.181	22.552	22.678	22.512	22.026	21.207	20.074
18.676	17.049	15.233	13.224	11.008	8.574	5.926	3.110
.195	-2.732	-5.615	-8.413	-11.118	-13.764	-16.376	-18.986
-21.550	-24.075	-26.518	-28.868	-31.116	-33.344	-35.585	-37.877
-40.220	-42.612	-45.064	-47.577	-50.196	-52.990	-56.032	-59.394
-63.123	-67.227	-71.679	-76.465	-81.568	-87.004	-92.800	-98.984
-105.588	-112.601	-119.990	-127.708	-135.705	-143.951	-152.401	-161.050
-169.847	-178.719	-187.590	-196.342	-204.888	-213.137	-221.043	-228.572
-235.713	-242.419	-248.630	-254.281	-259.285	-263.571	-267.092	-269.827
-271.768	-272.912	-273.258	-272.794	-271.510	-269.405	-266.492	-262.812
-258.415	-253.352	-247.661	-241.359	-234.460	-226.978	-218.929	-210.362
-201.346	-191.959	-182.279	-172.371	-162.290	-152.063	-141.724	-131.315

RUN 3

LONG TERM MTF OF THE ATMOSPHERE

1787646.2	1785938.5	1780822.0	1772323.0	1760482.2	1745356.2	1727018.2	1705554.7
1681069.7	1653680.0	1623515.7	1590721.7	1555452.2	1517872.0	1478155.7	1436483.7
1393045.5	1348034.5	1301650.5	1254097.7	1205582.7	1156312.0	1106490.0	1056319.0
1005998.1	955719.50	905671.88	856036.62	806989.50	758696.62	711314.37	664991.00
619852.25	576025.12	533615.63	492720.06	453422.19	415794.19	379895.25	345769.50
313450.31	282955.44	254291.84	227455.41	202432.37	179200.09	157726.50	137972.31
119888.44	103417.89	88496.031	75055.609	63023.898	52326.117	42886.648	34627.336
27470.137	21334.129	16138.961	11803.486	8250.271	5403.681	3194.004	1550.062
402.456	-303.787	-632.636	-641.394	-383.887	91.405	741.663	1528.023
2417.552	3378.699	4383.441	5405.696	6422.125	7413.246	8363.357	9261.135
10098.687	10869.766	11568.992	12192.943	12738.100	13202.928	13587.967	13895.924
14132.754	14303.482	14414.184	14469.088	14472.088	14426.656	14336.590	14208.873
14046.871	13861.637	13659.049	13444.641	13222.510	12995.064	12764.639	12533.646
12305.914	12085.207	11876.045	11680.775	11500.193	11333.475	11179.262	11036.441
10905.391	10787.613	10683.832	10595.934	10522.670	10461.641	10408.777	10360.971
10315.865	10272.070	10229.637	10189.648	10153.771	10116.049	10074.812	10025.732
9969.502	9904.924	9831.883	9751.088	9663.443	9568.273	9463.922	9347.660
9217.563	9072.695	8914.779	8746.398	8570.201	8387.496	8199.098	8003.727
7800.448	7588.061	7367.139	7140.500	6911.128	6681.239	6452.605	6224.679
5997.551	5769.643	5542.176	5316.739	5096.350	4883.546	4679.479	4484.902
4295.559	4111.550	3930.892	3753.640	3581.413	3416.695	3261.203	3115.270
2977.896	2846.650	2719.449	2595.197	2474.122	2357.396	2246.267	2141.520
2042.164	1945.943	1850.387	1754.595	1658.403	1563.214	1471.398	1384.535
1302.396	1223.705	1146.004	1066.740	985.315	902.280	820.533	741.631
665.160	595.144	529.190	465.733	403.782	344.035	288.305	238.959
198.042	165.853	141.626	123.358	109.738	100.005	95.835	100.022
115.065	142.460	181.760	231.355	288.438	351.058	418.864	492.748
574.897	666.563	768.380	878.899	996.327	1118.234	1243.859	1374.530
1509.727	1653.105	1804.443	1961.870	2123.139	2284.365	2443.511	2599.673
2753.863	2908.368	3064.426	3221.823	3378.795	3532.684	3679.607	3818.815
3949.301	4072.652	4189.171	4300.440	4405.067	4500.584	4584.672	4655.909
4716.795	4761.070	4802.537	4830.652	4856.926	4869.002	4872.316	0.000

RUN 3

SHORT TERM MTF OF THE ATMOSPHERE

1787646.2	1782230.5	1766084.5	1739515.7	1703024.7	1657288.7	1603146.0	1541566.2
1473625.7	1400474.7	1323307.2	1243328.2	1161721.0	1079618.5	998078.87	918059.38
840402.12	765817.87	694879.87	628022.75	565543.00	507605.81	454256.31	405433.19
360985.50	320688.31	284264.31	251400.25	221765.81	195029.34	170870.94	148997.12
129137.59	111070.73	94606.984	79596.812	65927.328	53517.461	42311.930	32274.168
23380.426	15610.396	8942.182	3346.300	-1219.216	-4811.179	-7502.373	-9380.240
-10546.38	-11113.26	-11201.05	-10931.67	-10426.68	-9801.781	-9160.836	-8593.234
-8169.332	-7938.653	-7929.545	-8149.484	-8586.289	-9212.072	-9983.271	-10851.11
-11757.62	-12632.94	-13415.64	-14044.73	-14467.55	-14641.76	-14538.06	-14142.59
-13453.94	-12484.39	-11256.45	-9801.342	-8157.185	-6367.749	-4480.472	-2544.378
-608.494	1281.388	3084.422	4768.081	6307.752	7687.098	8897.814	9937.693
10810.080	11521.584	12082.672	12505.729	12805.203	12996.031	13092.340	13108.154
13050.945	12930.121	12748.908	12508.396	12208.049	11845.840	11419.312	10926.178
10364.719	9733.762	9034.266	8268.719	7442.167	6561.742	5637.688	4682.184
3709.214	2734.493	1773.688	843.280	-41.107	-864.968	-1615.026	-2279.377
-2848.235	-3314.277	-3672.706	-3920.965	-4057.905	-4092.003	-4029.241	-3880.464
-3652.440	-3358.165	-3009.818	-2619.146	-2198.236	-1759.041	-1314.564	-877.723
-460.740	-73.849	275.512	582.965	847.738	1070.736	1254.070	1400.482
1512.621	1593.326	1646.618	1679.315	1699.565	1716.996	1741.529	1781.269
1842.491	1927.659	2037.674	2171.445	2327.517	2504.442	2700.047	2912.192
3134.235	3360.960	3583.376	3791.586	3975.979	4128.095	4241.121	4309.537
4329.185	4296.613	4209.160	4064.646	3862.159	3602.481	3287.504	2921.451
2509.146	2055.966	1567.871	1050.672	510.791	-45.375	-610.600	-1177.560
-1738.515	-2286.165	-2813.756	-3314.929	-3783.891	-4215.488	-4604.079	-4946.930
-5240.757	-5479.330	-5661.122	-5784.210	-5848.120	-5853.926	-5804.354	-5703.984
-5557.754	-5372.167	-5153.277	-4906.913	-4638.929	-4355.080	-4062.106	-3767.456
-3479.262	-3206.071	-2955.256	-2731.747	-2538.409	-2375.226	-2241.366	-2135.940
-2058.653	-2010.976	-1994.633	-2011.837	-2062.924	-2146.335	-2260.073	-2400.602
-2568.284	-2762.475	-2987.378	-3247.971	-3549.952	-3897.104	-4292.535	-4736.799
-5229.526	-5770.157	-6358.749	-6995.352	-7679.693	-8409.422	-9180.654	-9986.021
-10816.28	-11660.98	-12509.44	-13349.93	-14171.96	-14963.88	-15714.55	-16411.86
-17041.85	-17602.25	-18072.99	-18458.83	-18744.95	-18938.84	-19031.71	0.000

RUN 3

WANDER

5.700	-22.800	-42.750	-25.650	-51.300	-34.200	-25.650	-42.750
2.850	11.400	19.950	8.550	14.250	11.400	2.850	-11.400
-5.700	5.700	-5.700	19.950	0.000	31.350	42.750	17.100
31.350	42.750	42.750	28.500	39.900	54.150	54.150	51.300
57.000	71.250	51.300	54.150	48.450	31.350	31.350	39.900
42.750	51.300	31.350	25.650	45.600	51.300	57.000	48.450
45.600	31.350	42.750	37.050	51.300	54.150	31.350	31.350
17.100	31.350	51.300	51.300				

RUN 3

LONG TERM MTF OF THE ATMOSPHERE CALCULATED FROM FIT.

1891009.7	1890673.7	1889943.5	1888914.5	1887626.2	1886104.0	1884365.2	1882423.2
1880289.2	1877971.7	1875479.5	1872818.5	1869995.5	1867015.5	1863884.0	1860605.0
1857183.2	1853622.5	1849926.7	1846099.0	1842142.5	1838061.5	1833858.2	1829535.7
1825096.2	1820542.7	1815879.2	1811105.7	1806226.2	1801243.5	1796158.0	1790973.5
1785691.2	1780315.2	1774844.2	1769284.5	1763634.2	1757897.2	1752074.7	1746170.5
1740182.7	1734115.5	1727973.0	1721751.5	1715456.5	1709090.5	1702654.0	1696144.2
1689569.7	1682930.7	1676225.2	1669455.7	1662629.0	1655739.7	1648793.5	1641790.0
1634729.2	1627618.0	1620454.7	1613240.2	1605973.5	1598664.2	1591303.2	1583901.2
1576454.5	1568963.0	1561432.7	1553861.2	1546252.0	1538608.7	1530923.5	1523206.2
1515455.0	1507674.5	1499858.0	1492016.2	1484147.7	1476247.2	1468323.7	1460372.7
1452398.5	1444406.0	1436388.7	1428343.5	1420288.7	1412216.7	1404120.0	1396012.2
1387886.2	1379750.7	1371600.5	1363437.5	1355268.0	1347079.7	1338888.2	1330692.2
1322484.0	1314268.0	1306051.5	1297829.5	1289602.2	1281374.2	1273145.2	1264918.2
1256684.7	1248457.0	1240227.5	1232008.5	1223780.5	1215568.0	1207356.0	1199152.5
1190959.7	1182761.5	1174583.5	1166407.5	1158243.7	1150094.2	1141951.7	1133824.5
1125710.7	1117606.5	1109516.2	1101438.2	1093384.2	1085340.0	1077312.7	1069301.2
1061314.0	1053342.2	1045387.7	1037455.0	1029538.7	1021647.2	1013772.0	1005920.9
998095.37	990293.12	982512.37	974754.37	967027.00	959314.87	951628.37	943972.75
936343.12	928735.75	921162.87	913611.87	906096.75	898598.12	891138.62	883697.50
876293.62	868924.25	861576.37	854261.37	846973.00	839726.75	832501.62	825316.50
818158.00	811037.87	803942.25	796886.50	789860.25	782864.75	775911.25	768985.87
762096.88	755252.37	748426.87	741643.75	734895.50	728183.62	721508.00	714866.12
708261.87	701696.12	695161.75	688663.25	682208.37	675786.62	669402.12	663055.25
656743.25	650470.00	644239.75	638041.75	631883.62	625762.62	619674.87	613628.87
607620.62	601654.62	595723.50	589828.13	583972.12	578163.25	572383.50	566648.12
560945.87	555285.12	549661.87	544080.12	538533.25	533024.75	527555.12	522124.44
516736.62	511388.31	506065.31	500792.94	495557.06	490361.81	485199.56	480084.50
475000.37	469946.82	464947.37	459979.06	455048.87	450162.94	445298.69	440489.19
435710.87	430970.81	426266.37	421603.69	416979.56	412390.81	407834.25	403319.81
398847.44	394397.44	389996.12	385633.87	381307.31	377009.87	372754.81	368532.19
364342.37	360201.00	356079.62	352009.87	347966.37	343958.81	339993.25	336051.06
332150.50	328291.94	324459.94	320666.50	316899.69	313174.25	309481.25	305826.50
302201.31	298605.44	295053.50	291525.06	288037.19	284575.87	281155.00	277757.69
274400.50	271072.37	267778.56	264510.81	261280.09	258080.72	254915.69	251773.03
248667.28	245595.34	242543.69	239533.09	236545.34	233597.62	230670.50	227776.75
224909.78	222070.94	219269.50	216490.03	213740.12	211022.44	208329.00	205664.81
203029.56	200418.72	197843.59	195285.31	192757.75	190261.00	187790.09	185344.97
182925.34	180531.09	178171.41	175825.41	173509.00	171217.62	168955.16	166715.12
164501.84	162314.87	160145.66	158006.78	155885.47	153796.12	151722.16	149675.72
147658.41	145656.25	143677.06	141724.53	139792.72	137881.31	135994.25	134129.44
132288.50	130467.34	128664.27	126884.50	125127.94	123391.08	121674.75	119975.94
118301.39	116644.02	115008.75	113393.50	111795.06	110216.47	108658.14	107122.03
105599.34	104097.55	102612.91	101145.81	99703.812	98272.578	96860.000	95467.234
94089.594	92728.625	91388.469	90064.375	88754.984	87463.094	86186.969	84926.531
83684.406	82456.281	81243.469	80051.141	78868.438	77704.484	76551.312	75416.656
74296.406	73189.219	72098.656	71020.828	69955.797	68908.219	67873.937	66853.547
65843.750	64849.727	63867.617	62899.516	61944.484	61003.086	60073.336	59154.664
58250.695	57358.977	56476.914	55609.109	54753.156	53908.703	53074.914	52251.578
51442.547	50644.602	49856.047	49078.242	48312.320	47558.062	46812.523	46077.492
45352.844	44638.516	43934.328	43239.312	42555.102	41880.719	41216.000	40560.086
39913.656	39277.430	38648.859	38029.437	37419.922	36818.562	36225.289	35641.586
35065.687	34499.312	33939.727	33389.891	32847.734	32312.836	31786.176	31267.324
30756.395	30251.926	29755.898	29267.418	28785.000	28311.184	27843.496	27383.687
26929.781	26482.945	26042.484	25610.012	25183.141	24762.289	24348.781	23941.172
23538.930	23144.129	22754.520	22372.191	21993.859	21622.652	21256.348	20897.969
20542.344	20193.496	19849.301	19509.816	19176.762	18849.121	18527.766	18208.086

RUN 3

SHORT TERM MTF OF THE ATMOSPHERE CALCULATED FROM FIT.

2020644.0	2020480.2	2020131.2	2019645.0	2019042.7	2018336.5	2017535.2	2016645.5
2015672.5	2014621.0	2013495.0	2012297.5	2011031.5	2009699.5	2008303.7	2006846.5
2005329.5	2003755.0	2002124.2	2000438.5	1998699.7	1996909.0	1995067.7	1993177.0
1991238.0	1989251.2	1987219.0	1985141.0	1983019.0	1980853.7	1978645.5	1976395.7
1974104.7	1971774.5	1969403.7	1966995.7	1964548.7	1962064.7	1959544.0	1956987.7
1954395.5	1951768.0	1949108.0	1946412.7	1943685.2	1940925.7	1938134.2	1935309.5
1932455.5	1929571.5	1926657.0	1923712.0	1920740.0	1917738.2	1914709.0	1911652.0
1908566.5	1905456.2	1902319.2	1899156.5	1895966.7	1892754.5	1889515.2	1886253.5
1882967.2	1879656.7	1876324.0	1872967.7	1869589.7	1866190.5	1862767.2	1859323.5
1855858.7	1852374.5	1848867.5	1845342.5	1841799.0	1838233.5	1834650.2	1831047.5
1827426.2	1823789.2	1820132.7	1816455.0	1812764.7	1809058.0	1805331.0	1801589.7
1797831.2	1794059.0	1790270.2	1786466.0	1782648.5	1778812.2	1774964.2	1771104.2
1767227.5	1763335.7	1759433.0	1755516.5	1751586.2	1747644.0	1743689.5	1739724.2
1735743.5	1731753.2	1727750.0	1723739.0	1719710.7	1715677.2	1711630.7	1707575.0
1703511.5	1699431.0	1695347.0	1691250.0	1687144.5	1683032.2	1678909.0	1674778.5
1670640.2	1666491.5	1662334.5	1658168.7	1653999.7	1649819.7	1645633.0	1641438.2
1637240.2	1633033.7	1628819.7	1624600.2	1620373.0	1616142.0	1611902.2	1607658.2
1603410.5	1599158.0	1594899.0	1590634.7	1586369.2	1582093.2	1577813.5	1573532.2
1569246.5	1564954.5	1560663.0	1556354.7	1552067.5	1547760.5	1543455.7	1539142.0
1534830.0	1530518.5	1526198.5	1521877.7	1517552.0	1513231.0	1508901.7	1504575.5
1500244.2	1495914.7	1491579.0	1487246.5	1482909.7	1478570.5	1474235.5	1469896.0
1465557.0	1461224.5	1456880.7	1452542.0	1448202.7	1443863.7	1439525.7	1435186.5
1430848.7	1426512.0	1422173.0	1417834.7	1413502.0	1409167.7	1404834.7	1400503.5
1396171.5	1391842.0	1387518.0	1383191.7	1378869.2	1374547.5	1370224.7	1365906.5
1361590.0	1357279.5	1352968.8	1348658.5	1344351.2	1340054.0	1335752.2	1331458.0
1327162.5	1322872.0	1318584.2	1314302.2	1310020.2	1305741.7	1301467.0	1297196.2
1292932.7	1288674.0	1284407.5	1280155.7	1275906.3	1271662.5	1267418.5	1263187.2
1258952.7	1254715.7	1250498.7	1246279.5	1242064.5	1237861.0	1233646.0	1229452.7
1225257.7	1221068.7	1216883.0	1212705.7	1208535.7	1204368.7	1200202.2	1196046.0
1191900.2	1187746.0	1183609.0	1179480.5	1175356.5	1171231.0	1167117.7	1163006.5
1158897.7	1154808.2	1150708.0	1146631.5	1142551.0	1138477.2	1134417.2	1130350.5
1126298.5	1122260.7	1118220.2	1114191.2	1110159.5	1106143.2	1102132.0	1098133.0
1094135.7	1090140.2	1086164.7	1082184.2	1078220.5	1074255.7	1070308.0	1066356.0
1062421.2	1058490.0	1054569.0	1050648.0	1046741.0	1042842.0	1038953.9	1035062.7
1031187.2	1027322.1	1023451.4	1019603.7	1015752.9	1011924.7	1008092.4	1004271.1
1000455.0	996645.12	992855.50	989063.62	985281.12	981513.00	977746.12	973989.87
970243.87	966499.50	962777.12	959046.37	955329.62	951627.87	947932.50	944245.00
940564.12	936890.63	933240.00	929577.37	925930.25	922291.25	918667.12	915047.50
911439.62	907844.00	904245.00	900665.75	897083.37	893525.12	889960.12	886411.37
882883.37	879348.75	875823.12	872314.25	868811.12	865312.87	861828.13	858352.87
854891.62	851435.62	847981.25	844540.87	841114.62	837694.25	834283.87	830875.75
827486.00	824098.37	820725.50	817362.50	814002.50	810653.25	807314.50	803994.62
800669.87	797359.62	794056.62	790760.12	787491.12	784213.37	780947.25	777696.00
774448.12	771208.25	767987.37	764774.12	761564.62	758367.00	755177.00	751994.87
748828.37	745666.25	742512.00	739381.62	736243.50	733125.25	730003.62	726902.37
723809.00	720720.62	717648.12	714580.12	711516.50	708473.62	705439.50	702414.12
699389.12	696381.25	693378.13	690387.87	687406.25	684438.00	681474.37	678516.00
675574.50	672642.25	669711.12	666797.12	663892.25	660996.88	658106.50	655221.88
652358.25	649504.50	646651.75	643808.62	640979.12	638162.87	635348.50	632543.62
629748.37	626963.00	624187.37	621417.50	618661.12	615914.62	613177.87	610447.25
607726.37	605019.50	602314.75	599619.87	596938.87	594264.00	591595.37	588940.63
586291.87	583657.37	581024.87	578410.62	575802.62	573200.50	570609.00	568028.37
565457.12	562888.62	560334.38	557790.12	555248.75	552725.37	550204.62	547698.00
545194.12	542700.62	540213.87	537744.87	535279.00	532819.25	530374.62	527936.12
525501.00	523083.37	520669.44	518272.56	515871.94	513488.06	511108.56	508754.81
506387.94	504040.25	501694.25	499352.75	497029.50	494715.37	492420.44	490106.44

OPTICS DIFFRACTION PATTERN

1.000	.034	.042	.002	.002	.002	.000	.000
.000	.000	.000	.000	.000	.000	.000	.000
.000	.000	.000	.000	.000	.000		

LSF OF OPTICS DIFFRACTION

1.164	.185	.134	.018	.016	.011	.002	.002
.002	.001	.001	.001	.002	.001	.001	.001
.000	.000	.000	.000	.000			

INPUT DATA

1	! IO -- output specifier
120 376 374 118	! XW1 XW2 YW1 YW2 -- Quantex window parameters
216 280 60	! NL NU NA -- Scan range;No. of fields averaged
2.85	! SCALE -- scaling parameter (microradians/pixel)
.2032	! DOPT -- diameter of optics (meters)
.345	! OBS -- obscuration ratio
.6328E-06	! WAV -- wavelength of laser light (meters)
1147.	! RANGE -- laser propagation path length (meters)
5.	! SSIGMA -- (not used)
1.	! A -- (not used)

1

;

MTF OF TV

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APPENDIX D. SOURCE CODE LISTINGS FOR DATA ANALYSIS PROGRAMS

This appendix contains the source code listings of the main modules of MTFLTV, MTFLD, and PREDICT, of each secondary module, and of the command file COMP&LINK.CMD.

```

FTN7X,L,Q
$FILES(0,2)
PROGRAM MTFLTV

C
C   This program calculates the path weighted Cn parameters from short term,
C   long term and wander data observed by a vidicon looking through
C   a telescope directly at a HeNe laser source some distance away.
C
C DLTA(512)= The data used for long term calculations
C DSTA(512)= The data used for short term calculations
C DLTII(512)= The calculated diffraction function of the designator optics
C DSTI(512)= The source distribution function of the designator
C DWD(512)= The wander data
C DWDI(512)= ***** not presently used *****
C WAV= Wavelength of the designator radiation
C DOPT= Diameter of the designator optics
C OBS= Obscuration ratio of the designator optics
C SCALE= Scale of viewing telescope in microradians per TV line
C SSIGMA= ***** not used in this program *****
C RANGE= The distance from the designator to target
C KS= A parameter that indicates the highest term in the calculated
C     data that has significance.
C IDATE(20)= Information on the time and date of run
C ICMTS(20)= Comments about the run
C IWEATH(20)= Comments about the weather at time of run
C LU= Logical unit number for output terminal
C LI= Logical unit number for input terminal
C NA= Total number of video frames averaged
C NL= The smallest pixel number in a scan line that is summed
C NC= The largest pixel number in a scan line that is summed
C IO= Outputs the data and all calculations to files 30 to 50
C
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
COMMON /WINDOW/XW1,XW2,YW1,YW2,NFLDS

C
C   Input general data about the run
C
CALL GINPUT(1,IO)

C
C   Input data from the video digitizer and set up the long term,
C   short term and wander data blocks.
C   Currently, the number of data points is set to 256.
C
NPTS=256
CALL DINPUT(NPTS,DLTA,DSTA,DWD)
IF(IO.EQ.1) CALL OUTPUT(1,NPTS,DLTA)
IF(IO.EQ.1) CALL OUTPUT(2,NPTS,DSTA)
IF(IO.EQ.1) CALL OUTPUT(18,NFLDS,DWD)

C
C   Center the long and short term line spread functions
C
N=NPTS
CALL LSFS(N,DLTA)
IF(IO.EQ.1) CALL OUTPUT(3,N,DLTA)
N=NPTS
CALL LSFS(N,DSTA)
IF(IO.EQ.1) CALL OUTPUT(4,N,DSTA)

C
C   Take the fast Fourier transforms of the long and short term
C   line spread functions to obtain the optical system MTFs

```

```

C
N=NPTS
CALL FFT(0,N,DLTA)
IF(IO.EQ.1) CALL OUTPUT(5,N,DLTA)
N=NPTS
CALL FFT(0,N,DSTA)
IF(IO.EQ.1) CALL OUTPUT(6,N,DSTA)

C
C
C
Calculate the diffraction pattern, the line spread function,
and the MTF of the telescope optics

N=NPTS
CALL OPTICS(N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(10,N,DLTI)
CALL LSF(N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(11,N,DLTI)
N=NPTS
CALL FFT(0,N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(12,N,DLTI)

C
C
C
Obtain the MTF of the TV system

N=NPTS
CALL TVMTF(N,DSTI)
IF(IO.EQ.1) CALL OUTPUT(14,N,DSTI)

C
C
C
C
Multiply the telescope optics MTF by the TV system MTF to
obtain the combined MTF

CALL MUL(N,DSTI,DLTI)
IF(IO.EQ.1) CALL OUTPUT(15,N,DSTI)

C
C
C
C
Divide the overall system MTFs for long and short term data by
the combined telescope optics and TV system MTF to obtain the
MTF of the atmosphere

CALL DIVIDE(N,DSTA,DSTI)
IF(IO.EQ.1) CALL OUTPUT(16,N,DSTA)
CALL DIVIDE(N,DLTA,DSTI)
IF(IO.EQ.1) CALL OUTPUT(17,N,DLTA)

C
C
C
C
Calculate the Cn**2 values from the long and short term data
by fitting the atmospheric MTFs to Fried's model

CALL FIT(0,CNSQLT,COEFFLT,N,DLTA)
CALL FIT(1,CNSQST,COEFFST,N,DSTA)

C
C
C
C
Calculate Cn**2 from the laser spot wander data

CALL WANDER(CNSQWA,NFLDS,DWD)

C
C
C
Output the Cn**2 values to a file and to the operator's terminal

OPEN(905,FILE='OUTPUTCN.DAT')
WRITE(905,100) CNSQST,CNSQLT,CNSQWA
CLOSE(905)
100 FORMAT(' Cn**2 measured from short term = ',E11.4,/,
# ' Cn**2 measured from long term = ',E11.4,/,
# ' Cn**2 measured from wander = ',E11.4)
SCALE=10.0*SCALE
C

```

C Recalculate the long and short term atmospheric MTFs
C using the values of C_n^{**2} just found .
C

CALL AMTF(0,CNSQLT,COEFFLT,NPTS,DLTA)
CALL AMTF(1,CNSQST,COEFFST,NPTS,DSTA)
IF(IO.EQ.1) CALL OUTPUT(20,NPTS,DLTA)
IF(IO.EQ.1) CALL OUTPUT(21,NPTS,DSTA)
STOP
END

```

FTN7X,L,Q
$FILES(0,2)
PROGRAM MTFLD

C
C   This program calculates the path weighted Cn parameters from short term,
C   long term and wander data observed by a vidicon looking at the
C   spot pattern produced by a laser designator
C
C DLTA(512)= The data used for long term calculations
C DSTA(512)= The data used for short term calculations
C DLTI(512)= The calculated diffraction function of the designator optics
C DSTI(512)= The source distribution function of the designator
C DWD(512)= The wander data
C DWDI(512)= ***** not presently used *****
C WAV= Wavelength of the designator radiation
C DOPT= Diameter of the designator optics
C OBS= Obscuration ratio of the designator optics
C SCALE= Scale of viewing telescope in microradians per TV line
C SSIGMA= ***** not used in this program *****
C RANGE= The distance from the designator to target
C KS= A parameter that indicates the highest term in the calculated
C     data that has significance
C IDATE(20)= Information on the time and date of run
C ICMTS(20)= Comments about the run
C IWEATH(20)= Comments about the weather at time of run
C LU= Logical unit number for output terminal
C LI= Logical unit number for input terminal
C NA= Total number of video frames averaged
C NL= The smallest pixel number in a scan line that is summed
C NC= The largest pixel number in a scan line that is summed
C IO= Outputs the data and all calculations to files 30 to 50
C
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
COMMON /WINDOW/XW1,XW2,YW1,YW2,NFLDS

C
C   Input general data about the run
C
CALL GINPUT(2,IO)

C
C   Input data from the video digitizer and set up the long term,
C   short term and wander data blocks.
C   Currently, the number of data points is set to 256.
C
NPTS=256
CALL DINPUT(NPTS,DLTA,DSTA,DWD)
IF(IO.EQ.1) CALL OUTPUT(1,NPTS,DLTA)
IF(IO.EQ.1) CALL OUTPUT(2,NPTS,DSTA)
IF(IO.EQ.1) CALL OUTPUT(18,NFLDS,DWD)

C
C   Center the long and short term line spread functions
C
N=NPTS
CALL LSFS(N,DLTA)
IF(IO.EQ.1) CALL OUTPUT(3,N,DLTA)
N=NPTS
CALL LSFS(N,DSTA)
IF(IO.EQ.1) CALL OUTPUT(4,N,DSTA)

C
C   Take the fast Fourier transforms of the long and short term
C   line spread functions to obtain the optical system MTFs

```

```

C
N=NPTS
CALL FFT(0,N,DLTA)
IF(IO.EQ.1) CALL OUTPUT(5,N,DLTA)
N=NPTS
CALL FFT(0,N,DSTA)
IF(IO.EQ.1) CALL OUTPUT(6,N,DSTA)

C
C Calculate the laser source function assuming it has a Gaussian
C energy distribution
C
N=NPTS
CALL SOURCE(N,DSTI)
IF(IO.EQ.1) CALL OUTPUT(7,N,DSTI)

C
C Calculate the line spread function and the MTF of the source
C
CALL LSF(N,DSTI)
IF(IO.EQ.1) CALL OUTPUT(8,N,DSTI)
N=NPTS
CALL FFT(0,N,DSTI)
IF(IO.EQ.1) CALL OUTPUT(9,N,DSTI)

C
C Calculate the diffraction pattern, the line spread function,
C and the MTF of the telescope optics
C
N=NPTS
CALL OPTICS(N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(10,N,DLTI)
CALL LSF(N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(11,N,DLTI)
N=NPTS
CALL FFT(0,N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(12,N,DLTI)

C
C Multiply the source and optics MTFs to obtain their combined MTF
C
CALL MUL(N,DSTI,DLTI)
IF(IO.EQ.1) CALL OUTPUT(13,N,DSTI)

C
C Obtain the MTF of the TV system
C
CALL TVMTF(N,DLTI)
IF(IO.EQ.1) CALL OUTPUT(14,N,DLTI)

C
C Multiply the source-optics MTF by the TV system MTF to
C obtain their combined MTF
C
CALL MUL(N,DSTI,DLTI)
IF(IO.EQ.1) CALL OUTPUT(15,N,DSTI)

C
C Divide the overall system MTFs for long and short term data by
C the combined source-optics-TV system MTF to obtain the
C MTF of the atmosphere
C
CALL DIVIDE(N,DSTA,DSTI)
IF(IO.EQ.1) CALL OUTPUT(16,N,DSTA)
CALL DIVIDE(N,DLTA,DSTI)
IF(IO.EQ.1) CALL OUTPUT(17,N,DLTA)

C
C Calculate the  $C_n^{**2}$  values from the long and short term data

```

```

C   by fitting the atmospheric MTFs to Fried's model
C
CALL FIT(0,CNSQLT,COEFFLT,N,DLTA)
CALL FIT(1,CNSQST,COEFFST,N,DSTA)
C
C   Calculate Cn**2 from the laser spot wander data
C
CALL WANDER(CNSQWA,NFLDS,DWD)
C
C   Output the Cn**2 values to a file and to the operator's terminal
C
OPEN(905,FILE='OUTPUTCN.DAT')
WRITE(905,100) CNSQST,CNSQLT,CNSQWA
CLOSE(905)
100 FORMAT(' Cn**2 measured from short term = ',E11.4,/,
#       ' Cn**2 measured from long term = ',E11.4,/,
#       ' Cn**2 measured from wander = ',E11.4)
SCALE=10.0*SCALE
C
C   Recalculate the long and short term atmospheric MTFs
C   - using the values of Cn**2 just found
C
CALL AMTF(0,CNSQLT,COEFFLT,NPTS,DLTA)
CALL AMTF(1,CNSQST,COEFFST,NPTS,DSTA)
IF(IO.EQ.1) CALL OUTPUT(20,NPTS,DLTA)
IF(IO.EQ.1) CALL OUTPUT(21,NPTS,DSTA)
STOP
END

```

```

FTN7X,L,Q
$FILES(0,2)
PROGRAM PREDICT
C
C Predicts the performance of an optical projection system in
C a turbulent atmosphere.
C
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
COMMON /PPARMS/LSOURCE,LOPTICS,CNSQ
REAL FN1(512),FN2(512)
DATA IU,IOU/5,8/
C
C Input general program parameters
C
LNORM=0
NPTS=256
CALL GINPUT(3,IO)
IF(LSOURCE .NE. 3) THEN
  IF(LSOURCE .EQ. 1) THEN
    N=NPTS
    CALL SOURCE(N,FN1)
    IF(IO .EQ. 1) CALL POUTPUT(1,N,FN1)
  ELSE IF(LSOURCE .EQ. 2) THEN
    OPEN(901,FILE='SOURCE.DAT')
    READ(901,*) (FN1(I), I=1,NPTS)
    CLOSE(901)
  ENDIF
C
C Convert PSF of source to LSF
C
CALL LSF(NPTS,FN1)
IF(IO .EQ. 1) CALL POUTPUT(2,NPTS,FN1)
C
C Calculate the source MTF
C
N=NPTS
CALL FFT(0,N,FN1)
IF(IO .EQ. 1) CALL POUTPUT(3,N,FN1)
IF(LOPTICS .EQ. 1) THEN
C
C Calculate the optics diffraction pattern if not input from file
C
N=NPTS
CALL OPTICS(N,FN2)
IF(IO .EQ. 1) CALL POUTPUT(4,N,FN2)
ELSE IF(LOPTICS .EQ. 2) THEN
C
C Input optics diffraction pattern from data file if not calculated
C
OPEN(901,FILE='OPTICS.DAT')
READ(901,*) (FN2(I), I=1,NPTS)
CLOSE(901)
ENDIF
C
C Convert diffraction pattern (PSF) of optics to an LSF
C
CALL LSF(NPTS,FN2)
IF(IO .EQ. 1) CALL POUTPUT(5,NPTS,FN2)
C
C Calculate the optics MTF

```

```

C      N=NPTS
C      CALL FFT(0,N,FN2)
C
C      Normalize the optics MTF
C
C      DIV=FN2(1)
C      DO I=1,N
C          FN2(I)=FN2(I)/DIV
C      END DO
C      IF(IO .EQ. 1) CALL POUTPUT(6,N,FN2)
C
C      Multiply the source and optics MTFs to obtain their combined MTF
C
C      CALL MUL(N,FN1,FN2)
C      IF(IO .EQ. 1) CALL POUTPUT(7,N,FN1)
C      ELSE
C
C      Input source-optics MTF
C
C      OPEN(901,FILE='SRC&OPT.DAT')
C      READ(901,*) (FN1(I), I=1,NPTS)
C      CLOSE(901)
C      ENDIF
C
C      Calculate the atmospheric MTF -- long term
C
C      CALL AMTF(0,SQCN,-1.,NPTS,FN2)
C      IF(IO .EQ. 1) CALL POUTPUT(8,NPTS,FN2)
C
C      Multiply the source-optics MTF by the atmospheric MTF to obtain
C      the overall MTF -- long term
C
C      CALL MUL(NPTS,FN2,FN1)
C      IF(IO .EQ. 1) CALL POUTPUT(9,NPTS,FN2)
C
C      Calculate the image LSF by taking the inverse Fourier transform
C      of the overall MTF -- long term
C
C      N=NPTS
C      CALL FFT(1,N,FN2)
C      IF(IO .EQ. 1) CALL POUTPUT(10,N,FN2)
C
C      Convert the image LSF to a PSF -- long term
C
C      CALL ABEL(N,FN2)
C      CALL POUTPUT(11,N,FN2)
C
C      Calculate the radially integrated power -- long term
C
C      CALL INT(LNORM,N,FN2)
C      CALL POUTPUT(12,N,FN2)
C
C      Calculate the atmospheric MTF -- short term
C
C      CALL AMTF(1,SQCN,-1.,NPTS,FN2)
C      IF(IO .EQ. 1) CALL POUTPUT(13,NPTS,FN2)
C
C      Multiply the source-optics MTF by the atmospheric MTF to obtain
C      the overall MTF -- short term

```

```

CALL MUL(NPTS, FN2, FN1)
IF(IO .EQ. 1) CALL POUTPUT(14, NPTS, FN2)
C
C
C Calculate the image LSF by taking the inverse Fourier transform
of the overall MTF -- short term
N=NPTS
CALL FFT(1, N, FN2)
IF(IO .EQ. 1) CALL POUTPUT(15, N, FN2)
C
C
C Convert the image LSF to a PSF -- short term
CALL ABEL(N, FN2)
CALL POUTPUT(16, N, FN2)
C
C
C Calculate the radially integrated power -- short term
CALL INT(LNORM, N, FN2)
CALL POUTPUT(17, N, FN2)
C
C
C Output parameters to data file
OPEN(901, FILE='PARAMS.DAT')
WRITE(901, 1000) WAV, DOPT, OBS, SCALE, RANGE, CNSQ, EXT, A, SSIGMA
1000 FORMAT(//, ' Wavelength = ', E12.5, /, ' Diameter of optics = ',
#      E12.5, /, ' Obscuration ratio = ', E12.5, /, ' Scale = ', E12.5,
#      ' Range = ', E12.5, /, ' Cn**2 = ', E12.5, /, ' Extinction coe',
#      ' fficient = ', E12.5, /, ' Amplitude = ', E12.5, /, ' Sigma = ',
#      E12.5)
CLOSE(901)
STOP
END

```

FTN7X,L,Q

SUBROUTINE ABEL(NPTS,FN)

C

C

Converts a line spread function to a radially symmetric
point spread function

C

REAL FN(NPTS)

A=FN(1)

B=1.E-6*A

FN(1)=.2*(FN(1)-FN(2))

DO I=1,NPTS-2

C=FN(I+1)

FN(I+1)=.4*A+.2*C-.6*FN(I+2)

A=C

IF (ABS(A) .GT. B) N=I

END DO

DO I=1,N

FN(I)=FN(I)/(2.*SQRT((FLOAT(I)-.9)**2-(FLOAT(I-1))**2))

II=I+1

DO J=II,N

FN(I)=FN(I)+FN(J)/SQRT((FLOAT(J)-.9)**2-(FLOAT(I-1))**2)

END DO

FN(I)=FN(I)/3.14159

END DO

RETURN

END

```

FTN7X,L,Q
REAL FUNCTION AIRY(X)
C
C      Calculate the value of the Airy function of X.
C      AIRY(X) = 2*J1(X)/X where J1(X) is the Bessel function of order one.
C
      IF(X .EQ. 0.) THEN
        AIRY=1.
        RETURN
      ENDIF
      Z=0
      IF(X .LE. 15.) THEN
        J=20.+10.*X-X*X/3.
      ELSE
        J=90.+X/2.
      ENDIF
      IF(X .GE. 5.) THEN
        W=1.4*X+60./X
      ELSE
        W=X+6.
      ENDIF
      I=MAX1(W,(3.+X/4.))
      DO M=I,J,3
        V=1.E-28
        S=0.
        T=S
        F=1.-4.*(FLOAT(M)/2.-FLOAT(M/2))
        MM=M-2
        DO K=1,MM
          U=2.*FLOAT(M-K)*V/X-T
          T=V
          V=U
          IF((M-K-2) .EQ. 0) B=U
          F=-F
          FF=1.-F
          S=S+V*FF
        END DO
        U=2.*V/X-T
        S=S+U
        B=B/S
        IF((ABS(B-Z)-ABS(B*1.E-6)) .LT. 0.) GOTO 10
        Z=B
      END DO
10    AIRY=2.*B/X
      RETURN
      END

```

```

FTN7X,L,Q,J,S
  SUBROUTINE AMTF(R,EX,J)
C
C   Calculate the long and short term atmospheric MTF.
C   The result is then multiplied by the extinction factor EXP(-EXT*RANGE).
C
  DIMENSION R(512)
  COMMON/PARAMS/WAV,DOPT,OBS,SCALE,RANGE,SQCN,EXT,A,B
  AA=21.6*SQCN*RANGE*WAV**(-.3333333)
  IF(EX .LE. '0.') EX=EXP(-EXT*RANGE)
  D=0.
  R(1)=EX
  L=0
  DO I=2,512
    IF(L) 10,5,15
5      FF=976.56*(I-1)/SCALE
      ARG=AA*(FF**1.666667)
      IF(J.EQ.1) ARG=ARG*(1-(FF*WAV/OPT)**.3333333)
      IF(ARG .GT. 13.) L=1
      IF((ARG-D) .LT. 0.) L=-1
      R(I)=EX*EXP(-ARG)
      D=ARG
      M=I
      GO TO 20
0      R(I)=R(M)*(COS((I-M)*3.14159/M))**2
      IF(I.LT.3*M/2) GOTO 20
      L=1
15     R(I)=0.
20  END DO
    RETURN
  END

```

FTN7X,L,Q

SUBROUTINE BITINV(K,L,M)

C

C

Finds the bit inversion of an (M) bit number (K) to (L).

C

This is used in the Fourier transform subroutine.

C

L=0

DO I=0,M-1

IF(BTEST(K,I)) THEN L=IBSET(L,M-I)

END DO

RETURN

END

FTN7X,L,Q

SUBROUTINE DIGITIZE

C
C
C

Digitize a frame of video with the Quantex DS-30 (Store Input function)

INTEGER CODE(6)

DATA CODE/000001B,031040B,001056B,033500B,007452B,030500B/

DATA LUDS30/24/

CALL EXEC(2,2100B+LUDS30,CODE,-11)

RETURN

END

```

FTN7X,L,Q
CHARACTER*16 FUNCTION DIGITS(N,BASE)
C
C      Convert integer N to string of digits in base BASE (< 17)
C
  INTEGER N,BASE
  CHARACTER DIGIT*16,A*16
  DATA DIGIT/'0123456789ABCDEF'/
  IF(N .EQ. -32768) THEN
    M=0
  ELSE
    M=IABS(N)
  ENDIF
C
C      Determine last digit
C
  L=MOD(M,BASE)+1
  A(1:1)=DIGIT(L:L)
  M=M/BASE
  IF(N .LT. 0) M=M+2*(16384/BASE)
  I=1
C
C      Determine rest of digits
C
  DO WHILE (M .NE. 0)
    I=I+1
    L=MOD(M,BASE)+1
    A(I:I)=DIGIT(L:L)
    M=M/BASE
  END DO
C
C      Invert string A
C
  K=I+1
  DIGITS=' '
  DO J=1,I
    K=K-1
    DIGITS(J:J)=A(K:K)
  END DO
  RETURN
END

```

```

FTN7X,L,Q
SUBROUTINE DINPUT(NPTS,DLTA,DSTA,DWD)
C
C   This subroutine inputs data from the video digitizer and processes
C   it to provide the long term, short term and wander data for
C   further processing.
C
COMMON /WINDOW/XW1,XW2,YW1,YW2,NFLDS
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
REAL DLTA(NPTS),DSTA(NPTS),DWD(NFLDS),DLTI(512),DSTI(512)
INTEGER XW1,XW2,YW1,YW2,BEEP
DATA BEEP/003407B/
C
C   Initialize arrays
C
N2=NPTS/2
DO I=1,NPTS
    DLTA(I)=0.
    DSTA(I)=0.
    DLTI(I)=0.
    DSTI(I)=0.
END DO
DO I=1,NFLDS
    DWD(I)=0.
END DO
C
C   Perform summations of video data over NFLDS fields
C
DO I=1,NFLDS
    VINT=0.
    BASE=0.
    WRITE(1, '(A2)') BEEP
    WRITE(1, *)
    WRITE(1, *) ' Advance to field #', I, ' out of', NFLDS
    WRITE(1, *) ' Enter 1 when ready or 0 to stop: '
    READ(1, *) INPUT
    IF(INPUT .EQ. 0) STOP
C
C   Digitize one video field
C
CALL DIGITIZE
C
C   Obtain vertical video intensity profile by integrating
C   horizontal scan lines
C
DO J=1,NPTS
    CALL VIDEODATA(J,Z)
    DLTI(J)=Z
    VINT=VINT+Z
    IF(J .LE. 32 .OR. J .GE. NPTS-32) BASE=BASE+Z
END DO
BASE=BASE/64.
VINT=VINT-BASE*NPTS
SUM=0.
DO J=1,NPTS
    SUM=DLTI(J)+SUM-BASE
    IF(SUM .GT. VINT/2.) GOTO 10
END DO
J=N2
MIDPT=J
10

```

```

DO K=1,NPTS
  KK=K+MIDPT-N2
  IF(KK .LT. 1) KK=KK+NPTS
  IF(KK .GT. NPTS) KK=KK-NPTS
  DLTA(K)=DLTA(K)+DLTI(K)-BASE
  DSTA(K)=DSTA(K)+DLTI(KK)-BASE
END DO
DWD(I)=SCALE*(MIDPT-N2)
END DO
RETURN
END

```

FTN7X,L,Q,J,S

SUBROUTINE DIVIDE(N,ARRAY1,ARRAY2)

C

C

C

C

C

Divide the first N points of ARRAY1 by ARRAY2 and store the
result in ARRAY1. If the value of the divisor is zero,
then the result of the division is set to zero.

DIMENSION ARRAY1(N),ARRAY2(N)

DO I=1,N

IF(ARRAY2(I) .NE. 0.) THEN

ARRAY1(I)=ARRAY1(I)/ARRAY2(I)

ELSE

ARRAY1(I)=0.

ENDIF

END DO

RETURN

END

```

FTN7X,L,Q
SUBROUTINE FFT(LINV,NPTS,FN)
C
C      Fourier transform subroutine
C
IMPLICIT COMPLEX (C)
COMPLEX CE(512),CG(1024)
REAL FN(NPTS)
DATA IST,PI/0,3.1415927/
NN=2*NPTS+2
NEXP=NINT(ALOG(FLOAT(NPTS))/ALOG(2.))+1
TH=PI/NPTS
CG(1)=FN(1)
DO I=2,NPTS
    CG(I)=FN(I)
    CG(NN-I)=CG(I)
END DO
CG(NPTS+1)=CG(NPTS)
IF(IST.EQ. 0) THEN
    IST=1
    A=0.
    DO I=1,NPTS
        CE(I)=CEXP(CMPLX(0.,A))
        A=A+TH
    END DO
    CE(NPTS/2+1)=(0.,1.)
ENDIF
DO M=1,NEXP
    K=2**(NEXP-M)
    L=2**(M-1)
    DO LL=1,L
        KC=LL-1
        CALL BITINV (KC,N,NEXP-1)
        CD=CE(N+1)
        IF(LINV.EQ.1) CD=CONJG(CD)
        KL=2*KC*K+1
        KU=KL+K-1
        DO I=KL,KU
            CA=CG(I)+CG(I+K)*CD
            CG(I+K)=CG(I)-CG(I+K)*CD
            CG(I)=CA
        END DO
    END DO
END DO
NN=2*NPTS
DO I=1,NN
    J=I-1
    CALL BITINV (J,N,NEXP)
    IF(J.LT. N) THEN
        N=N+1
        CA=CG(I)/(32.,0.)
        CG(I)=CG(N)
        CG(N)=CA
    ELSE
        IF(J.EQ. N) CG(I)=CG(I)/(32.,0.)
    ENDIF
END DO
DO I=1,NPTS
    FN(I)=CG(I)
    IF(FN(I).GE. 1.E-6*FN(1)) LASTPT=I
END DO

```

AD-A171 899

OPTICAL TURBULENCE MEASUREMENT - INVESTIGATION FOR
ANALYSIS OF LASER DESI.. (U) ARMY ELECTRONIC PROVING
GROUND FORT HUACHUCA AZ E A MILNE ET AL. 14 FEB 86

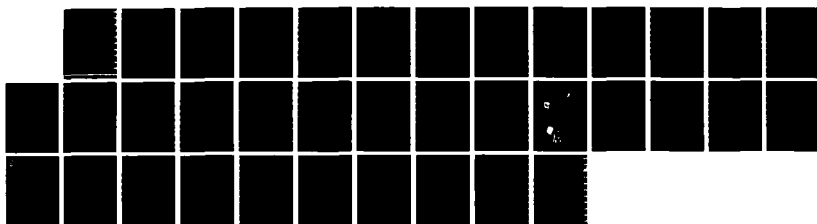
2/2

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NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NPTS=LASTPT
RETURN
END

```

FTN7X,L,Q,J,S
SUBROUTINE FIT(CNSQ,COEFF,NPTS,MTF)
C
C Find function parameters (Cn**2 and MTF coefficient) by performing
C a least squares fit of the MTF to Fried's model:
C MTF(X) = COEFF * EXP(CNSQ*X)
C

COMMON/PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,B
REAL MTF(NPTS)
SUMX=0.
SUMY=0.
SUMX2=0.
SUMXY=0.
POINTS=0.
DO I=1,NPTS
  IF(MTF(I) .LE. 0.) GOTO 10
  FF=976.56*FLOAT(I-1)/SCALE
  X=-21.6*FF**(1.666667)*RANGE*WAV**(-.3333333)
  Y=ALOG(MTF(I))
  POINTS=POINTS+1.
  SUMX=SUMX+X
  SUMX2=SUMX2+X*X
  SUMY=SUMY+Y
  SUMXY=SUMXY+X*Y
  IF(I .GE. 4) THEN
    IF(MTF(I) .GE. MTF(I-1) .OR. MTF(I) .LT. .1*MTF(1)) GOTO 10
  ENDIF
END DO
10 SQCN=(SUMXY*POINTS-SUMY*SUMX)/(SUMX2*POINTS-SUMX*SUMX)
COEFF=EXP((SUMX2*SUMY-SUMXY*SUMX)/(SUMX2*POINTS-SUMX*SUMX))
RETURN
END

```

[illegible]

This subroutine inputs the general data needed to process the run.

SCALE - scale of the system in micrometers per frame
line or field line

OBS - ratio of the diameter of the obscuration to the diameter of the objective

RANGE - the distance from the optics to the target

YW1,YW2 - bottom and top of data window

IO=0

IF(10 .EQ. 0) THEN

IV-5

```
OPEN(IU,FILE='INPUT.DAT')
```

```
READ(IU,*) IO
```

```
READ(IU,*) WAV
```

WAV=1.E-6*WAV

READ(IU,*) DOPT

READ(IU,*) OBS

READ(IU,*) SCALE

READ(IU,*) RANGE

IF(LPROG .LE. 2) THEN

```
READ(IU, '(A80)') HEADER1
```

```
READ(IU, '(A80)') HEADER2
```

READ(IU, '(A80)') DATE

```
READ(IU,*) XW1,XW2,YW2,YW1
```

READ(IU,*) NFLDS

ENDIF

```
IF(LPROG .EQ. 3) THEN
```

```
READ(IU,'(A80)') HEADER1
```

```
READ(IU, '(A80)') HEADER2
```

READ(IU,*) CNSQ

READ(IU,*) EXT

READ(IU,*) A

READ(IU,*) LSOURCE

READ(IU,*) LOPTICS

ENDIF

```
IF(LPROG .EQ. 2 .OR. LPROG .EQ. 3) THEN
```

READ(IU,*) SSIGMA

ENDIF

CLOSE(IU)

ELSE

CCC

Interactive input follows.

IU=1

```
WRITE(1,*)' Enter 1 for complete data output:'
```

```

READ(IU,*) IO
WRITE(1,*) ' Enter the wavelength in micrometers: '
READ(IU,*) WAV
WAV=1.E-6*WAV
WRITE(1,*) ' Enter diameter of the optics in meters: '
READ(IU,*) DOPT
WRITE(1,*) ' Enter obscuration ratio of optics: '
READ(IU,*) OBS
WRITE(1,*) ' Enter pixel resolution scale factor in ',
# ' microradians per pixel: '
READ(IU,*) SCALE
WRITE(1,*) ' Enter the range in meters: '
READ(IU,*) RANGE
IF(LPROG .LE. 2) THEN
  WRITE(1,*) ' Enter comments about run (for header): '
  READ(IU, '(A80)') HEADER1
  WRITE(1,*) ' Enter weather information: '
  READ(IU, '(A80)') HEADER2
  WRITE(1,*) ' Enter date and time of run: '
  READ(IU, '(A80)') DATE
  WRITE(1,*) ' Enter left pixel limit of image window: '
  READ(IU,*) XW1
  WRITE(1,*) ' Enter right pixel limit of image window: '
  READ(IU,*) XW2
  WRITE(1,*) ' Enter top pixel limit of image window: '
  READ(IU,*) YW2
  WRITE(1,*) ' Enter bottom pixel limit of image window: '
  READ(IU,*) YW1
  WRITE(1,*) ' Enter number of fields integrated: '
  READ(IU,*) NFLDS
ENDIF
IF(LPROG .EQ. 3) THEN
  WRITE(1,*) ' Enter information about source: '
  READ(1, '(A80)') HEADER1
  WRITE(1,*) ' Enter information about optics: '
  READ(1, '(A80)') HEADER2
  WRITE(1,*) ' Enter Cn**2 in meters**(-2/3): '
  READ(1,*) CNSQ
  WRITE(1,*) ' Enter extinction coefficient in meters**(-1): '
  READ(1,*) EXT
  WRITE(1,*) ' Enter maximum of source in Watts/steradian: '
  READ(1,*) A
  WRITE(1,*) ' Enter source option: 1 -- Gaussian; 2 -- Input; ',
# ' 3 -- Source-optics fn. input.'
  READ(1,*) LSOURCE
  WRITE(1,*) ' Enter optics diffraction option: 1 -- Computed; ',
# ' 2 -- Input.'
  READ(1,*) LOPTICS
ENDIF
IF(LPROG .EQ. 1 .OR. LPROG .EQ. 3) THEN
  WRITE(IU,100)
100  FORMAT(' Enter sigma of the designator laser.',/, ' This ',
# ' is the angle in radians where the intensity falls off to',/,
# ' 1/e of the peak intensity. ')
  READ(IU,*) SSIGMA
ENDIF
ENDIF
RETURN
END

```

```

FTN7X,L,Q,J,S
SUBROUTINE INT(LNORM,NPTS,FN)
C
C   Given the point spread function, calculate the power inside
C   a circle as a function of radius.
C   Will normalize the power function to the total power if LNORM=1.
C
COMMON /PARAMS/WAV,OPT,OBRA,SCALE,RANGE,EXT,A,B
REAL FN(NPTS)
C
C   Calculate the power function
C
R2=(SCALE*RANGE)**2
FN(1)=.7853982E-12*FN(1)*R2
DO I=2,NPTS
    FN(I)=FN(I-1)+6.28315E-12*FN(I)*R2*FLOAT(I-1)
END DO
C
C   Normalize the power function
C
IF(LNORM .EQ. 1) THEN
    DO I=1,NPTS
        FN(I)=FN(I)/FN(NPTS)
    END DO
ENDIF
RETURN
END

```

```

FTN7X,L,Q,J,S
SUBROUTINE LSF(NPTS,FN)
C
C   Convert a point spread function to a line spread function.
C
  REAL FN(NPTS)
  DO I=1,NPTS
    Z=FN(I)
    J=1
10   R=SQRT(FLOAT((I-1)**2+J*J))
    IR=IFIX(R)
    RI=FLOAT(IR)
    RF=R-RI
    Z=Z+2.*((1.-RF)*FN(IR+1)+RF*FN(IR+2))
    J=J+1
    IF(IR .LT. NPTS) GOTO 10
    FN(I)=Z
  END DO
  RETURN
END

```

FTN7X,L,Q

SUBROUTINE LSFS(NPTS,FN)

C

C

Shift a line spread function so that it is centered at the origin.

C

REAL FN(NPTS),T(512)

N2=NPTS/2

A=0.

DO I=1,NPTS

T(I)=FN(I)

A=FN(I)+A

END DO

S=0.

DO I=1,NPTS

S=S+T(I)

IF(S .GT. A/2.) GOTO 10

END DO

I=N2

10 DO J=1,N2

K1=I+J-1

K2=I-J+1

IF(K1 .GT. NPTS) K1=K1-NPTS

IF(K2 .LT. 1) K2=K2+NPTS

FN(J)=T(K1)+T(K2)

FN(J+N2)=0.

END DO

RETURN

END

FTN7X,L,Q,J,S

SUBROUTINE MUL(N,ARRAY1,ARRAY2)

C
C
C
C

Calculate the product of the first N points of ARRAY1 and ARRAY2
and store the result in ARRAY1.

DIMENSION ARRAY1(N),ARRAY2(N)

DO I=1,N

ARRAY1(I)=ARRAY1(I)*ARRAY2(I)

END DO

RETURN

END

```

FTN7X,L,Q,J,S
SUBROUTINE OPTICS(NPTS,FN)
C
C Calculate the optics diffraction pattern (point spread function)
C
COMMON //WAV,DOPT,OBS,SCALE,RANGE,SQCN,EXT,A,SSIGMA,IDATE(30),
# IHEAD(80)
REAL FN(NPTS)
INTEGER*2 IDATE,IHEAD
OB=OBS*OBS
OBA=(1.-OB)**2
Q=3.14159E-6*SCALE*DOPT/WAV
N=NPTS
DO I=1,N
    R=Q*FLOAT(I-1)
    IF(R .LE. 60.) THEN
        FN(I)=((AIRY(R)-OB*AIRY(R*OBS))**2)/OBA
        NPTS=I
    ELSE
        FN(I)=0.
    ENDIF
END DO
RETURN
END

```

```

FTN7X,L,Q
SUBROUTINE OUTPUT(LHEAD,NPTS,ARRAY)
C
C   Output intermediate and final results to files
C
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
COMMON /HEADER/HEADER1,HEADER2,DATE
REAL ARRAY(NPTS)
CHARACTER UNIT*5,FILE*11,DIGITS*16
CHARACTER*80 HEADER1,HEADER2,DATE,TITLE
C
C   Specify TITLE string, i.e. the title of this output data
C
IF(LHEAD .EQ. 1) THEN
    TITLE=' Optical System LSF -- Long Term'
ELSE IF(LHEAD .EQ. 2) THEN
    TITLE=' Optical System LSF -- Short Term'
ELSE IF(LHEAD .EQ. 3) THEN
    TITLE=' Centered LSF -- Long Term'
ELSE IF(LHEAD .EQ. 4) THEN
    TITLE=' Centered LSF -- Short Term'
ELSE IF(LHEAD .EQ. 5) THEN
    TITLE=' Optical System MTF -- Long Term'
ELSE IF(LHEAD .EQ. 6) THEN
    TITLE=' Optical System MTF -- Short Term'
ELSE IF(LHEAD .EQ. 7) THEN
    TITLE=' Source Distribution Function'
ELSE IF(LHEAD .EQ. 8) THEN
    TITLE=' LSF of Source Distribution Function'
ELSE IF(LHEAD .EQ. 9) THEN
    TITLE=' Fourier Transform of Source Distribution Function'
ELSE IF(LHEAD .EQ. 10) THEN
    TITLE=' Diffraction Pattern of Telescope Optics'
ELSE IF(LHEAD .EQ. 11) THEN
    TITLE=' LSF of Telescope Optics'
ELSE IF(LHEAD .EQ. 12) THEN
    TITLE=' MTF of Telescope Optics'
ELSE IF(LHEAD .EQ. 13) THEN
    TITLE=' Source and Optics Calibration Function'
ELSE IF(LHEAD .EQ. 14) THEN
    TITLE=' MTF of TV System'
ELSE IF(LHEAD .EQ. 15) THEN
    TITLE=' MTF of the Overall System'
ELSE IF(LHEAD .EQ. 16) THEN
    TITLE=' MTF of the Atmosphere -- Long Term'
ELSE IF(LHEAD .EQ. 17) THEN
    TITLE=' MTF of the Atmosphere -- Short Term'
ELSE IF(LHEAD .EQ. 18) THEN
    TITLE=' Wander of the Laser Spot Image'
ELSE IF(LHEAD .EQ. 19) THEN
    TITLE=' Fourier Transform of the Laser Spot Image Wander'
ELSE IF(LHEAD .EQ. 20) THEN
    TITLE=' MTF of the Atmosphere Calculated from Fitted Data'//
#    ' -- Long Term'
ELSE IF(LHEAD .EQ. 21) THEN
    TITLE=' MTF of the Atmosphere Calculated from Fitted Data'//
#    ' -- Short Term'
ENDIF
C
C   Specify I/O unit number and file name

```

C

```
IOU=900+LHEAD  
UNIT=DIGITS(LHEAD,10)  
FILE='OUTPUT'//UNIT
```

C

C

C

Output data to file

```
OPEN(IOU,FILE=FILE)  
WRITE(IOU,*) TITLE  
WRITE(IOU,*) HEADER1  
WRITE(IOU,*) HEADER2  
WRITE(IOU,*) DATE  
WRITE(IOU,'(8(1X,F9.3))') (ARRAY(I), I=1,NPTS)  
CLOSE(IOU)  
RETURN  
END
```

```

FTN7X,L,Q
SUBROUTINE POUTPUT(LHEAD,NPTS,ARRAY)
C
C   Output intermediate and final results to files
C
COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA
COMMON /HEADER/HEADER1,HEADER2,DATE
REAL ARRAY(NPTS)
CHARACTER UNIT*5,FILE*11,DIGITS*16
CHARACTER*80 HEADER1,HEADER2,DATE,TITLE
C
C   Specify TITLE string, i.e. the title of this output data
C
IF(LHEAD .EQ. 1) THEN
    TITLE=' Gaussian source function'
ELSE IF(LHEAD .EQ. 2) THEN
    TITLE=' Source line spread function'
ELSE IF(LHEAD .EQ. 3) THEN
    TITLE=' MTF of the source'
ELSE IF(LHEAD .EQ. 4) THEN
    TITLE=' Optics diffraction pattern'
ELSE IF(LHEAD .EQ. 5) THEN
    TITLE=' Optics line spread function'
ELSE IF(LHEAD .EQ. 6) THEN
    TITLE=' MTF of the optics'
ELSE IF(LHEAD .EQ. 7) THEN
    TITLE=' Combined source and optics MTF'
ELSE IF(LHEAD .EQ. 8) THEN
    TITLE=' Atmospheric MTF -- long term'
ELSE IF(LHEAD .EQ. 9) THEN
    TITLE=' Combined source, optics, and atmospheric MTF -- '//'
#   'long term'
ELSE IF(LHEAD .EQ. 10) THEN
    TITLE=' Image line spread function -- long term'
ELSE IF(LHEAD .EQ. 11) THEN
    TITLE=' Image point spread function -- long term'
ELSE IF(LHEAD .EQ. 12) THEN
    TITLE=' Radially integrated power of source -- long term'
ELSE IF(LHEAD .EQ. 13) THEN
    TITLE=' Atmospheric MTF -- short term'
ELSE IF(LHEAD .EQ. 14) THEN
    TITLE=' Combined source, optics, and atmospheric MTF -- '//'
#   'short term'
ELSE IF(LHEAD .EQ. 15) THEN
    TITLE=' Image line spread function -- short term'
ELSE IF(LHEAD .EQ. 16) THEN
    TITLE=' Image point spread function -- short term'
ELSE IF(LHEAD .EQ. 17) THEN
    TITLE=' Radially integrated power of source -- short term'
ENDIF
C
C   Specify I/O unit number and file name
C
IOU=900+LHEAD
UNIT=DIGITS(LHEAD,10)
FILE='OUTPUT'//UNIT
C
C   Output data to file
C
OPEN(IOU,FILE=FILE)

```

```
WRITE(10U,*) TITLE
WRITE(10U,*) HEADER1
WRITE(10U,*) HEADER2
WRITE(10U,*) DATE
WRITE(10U,'(8(1X,F9.3))') (ARRAY(I), I=1,NPTS)
CLOSE(10U)
RETURN
END
```

FTN7X,L,Q,J,S

SUBROUTINE SOURCE(NPTS,FN)

C
C
C
C
C

Calculates the values of a Gaussian source function having
a mean of zero, a spread of SSIGMA, and an amplitude
equal to A.

COMMON /PARAMS/WAV,DOPT,OBS,SCALE,RANGE,EXT,A,SSIGMA

REAL FN(NPTS)

DO I=1,NPTS

 X=SCALE*FLOAT(I-1)

 ARG=X*X/(2.*SSIGMA*SSIGMA)

 IF(ARG .LE. 70.) THEN

 FN(I)=A*EXP(-ARG)

 NPTS=I

 ELSE

 FN(I)=0.

 ENDIF

END DO

RETURN

END

FTN7X,L,Q

SUBROUTINE TVMTF(NPTS,FN)

C
C
C
C
C
C
C

Obtain the TV system MTF.

Note: For now this routine creates a step function with
the first 256 values of FN set to 1 and the
rest set to 0.

REAL FN(NPTS)

N=256

DO I=1,NPTS

IF(I .LT. N) THEN

FN(I)=1.

ELSE

FN(I)=0.

ENDIF

END DO

RETURN

END

FTN7X,L,Q

SUBROUTINE VIDEODATA(ROW,ROWSUM)

C
C
C

Read in a row of digitized video data and sum the data

```
COMMON /WINDOW/XW1,XW2,YW1,YW2,NFLDS
INTEGER ZDAT(512),ROW,QROW,QCOL,XW1,XW2,YW1,YW2
INTEGER CODE(9),LO_ADD,HI_ADD,WCOUNT
DATA LUDS30/24/,LUHPIB/207
DATA CODE/000001B,036442B,0,0,0,0,0,050140B,007400B/
NPIX=XW2-XW1+1
QROW=ROW+YW2-1
QCOL=XW1
LO_ADD=IAND(QCOL-1,255)
HI_ADD=2*(QROW-1)+IAND(QCOL-1,256)/256
WCOUNT=NPIX+1
CODE(3)=001040B+IAND(LO_ADD,15)
CODE(4)=030100B+IAND(LO_ADD,240)*16+IAND(HI_ADD,15)
CODE(5)=050140B+IAND(HI_ADD,240)*16+IAND(HI_ADD,3840)/256
CODE(6)=001440B+IAND(WCOUNT,15)
CODE(7)=030100B+IAND(WCOUNT,240)*16+IAND(WCOUNT,3840)/256
CALL ABRT(LUHPIB,2)
CALL EXEC(2,2100B+LUDS30,CODE,-17)
CALL EXEC(1,2100B+LUDS30,ZDAT,-NPIX)
ROWSUM=0.
DO I=1,NPIX,2
    ROWSUM=ROWSUM+IAND(ISHFT(ZDAT(I),0),377B)+
        IAND(ISHFT(ZDAT(I),-8),377B)
END DO
RETURN
END
```

```

FTN7X,L,Q,J,S
      SUBROUTINE WANDER(NPTS,FN)
C
C      Calculate the  $C_n^{**2}$  from the wander of the laser spot image
C
      COMMON //WAV,DOPT,OBS,SCALE,RANGE,SQCN,EXT,A,SSIGMA,IDATE(30),
#       IHEAD(80)
      REAL FN(NPTS)
      IF(NPTS .LE. 1) RETURN
      SUM=0.
      SUMSQ=0.
C
C      Calculate the sum of and the sum of the squares of the wander data
C
      DO I=1,NPTS
          SUM=SUM+FN(I)
          SUMSQ=SUMSQ+FN(I)*FN(I)
      END DO
C
C      Calculate the variance of the wander data
C
      VAR=(SUMSQ-SUM*SUM/FLOAT(NPTS))/FLOAT(NPTS-1)
C
C      Calculate the  $C_n^{**2}$  using the variance of the wander data
C
      SQCN=0.956E-12*SCALE*SCALE*VAR*DOPT**(0.3333333)/RANGE
      RETURN
      END

```

** COMP&LINK.CMD

```
*****
**
**
**      Command file for compiling and linking programs
**      MTFLTV,MTFLD and PREDICT
**
**
*****
**
**      Compile all of the program modules
**
FTN7X /MTF/ABEL.FTN 0 -
FTN7X /MTF/AIRY.FTN 0 -
FTN7X /MTF/AMTF.FTN 0 -
FTN7X /MTF/BITINV.FTN 0 -
FTN7X /MTF/DIGITIZE.FTN 0 -
FTN7X /MTF/DIGITS.FTN 0 -
FTN7X /MTF/DINPUT.FTN 0 -
FTN7X /MTF/DIVIDE.FTN 0 -
FTN7X /MTF/FFT.FTN 0 -
FTN7X /MTF/FIT.FTN 0 -
FTN7X /MTF/GINPUT.FTN 0 -
FTN7X /MTF/INT.FTN 0 -
FTN7X /MTF/LSF.FTN 0 -
FTN7X /MTF/LSFS.FTN 0 -
FTN7X /MTF/MTFLD.FTN 0 -
FTN7X /MTF/MTFLTV.FTN 0 -
FTN7X /MTF/MUL.FTN 0 -
FTN7X /MTF/OPTICS.FTN 0 -
FTN7X /MTF/OUTPUT.FTN 0 -
FTN7X /MTF/POUTPUT.FTN 0 -
FTN7X /MTF/PREDICT.FTN 0 -
FTN7X /MTF/SOURCE.FTN 0 -
FTN7X /MTF/TVMTF.FTN 0 -
FTN7X /MTF/VIDEODATA.FTN 0 -
FTN7X /MTF/WANDER.FTN 0 -
**
**      Merge the relocatable code files into file MTF.REL.
**      File MERGE.CMD contains a list of the files to be merged.
**
MERGE /MTF/MERGE.CMD /MTF/MTF.REL
**
**      Create an indexed library of the relocatable code modules
**
LINDX /MTF/MTF.REL /MTF/MTF.LIB
**
**      Purge the relocatable code files
**
PU /MTF/MTF.REL
PU /MTF/ABEL.REL
PU /MTF/AIRY.REL
PU /MTF/AMTF.REL
PU /MTF/BITINV.REL
PU /MTF/DIGITS.REL
PU /MTF/DIGITIZE.REL
PU /MTF/DINPUT.REL
PU /MTF/DIVIDE.REL
PU /MTF/FFT.REL
PU /MTF/FIT.REL
PU /MTF/GINPUT.REL
```

PU /MTF/INT.REL
PU /MTF/LSF.REL
PU /MTF/LSFS.REL
PU /MTF/MUL.REL
PU /MTF/OPTICS.REL
PU /MTF/OUTPUT.REL
PU /MTF/POUTPUT.REL
PU /MTF/SOURCE.REL
PU /MTF/TVMTF.REL
PU /MTF/VIDEODATA.REL
PU /MTF/WANDER.REL

**

**

Link the programs

**

LINK /MTF/MTFLT.V.FTN /MTF/MTF.LIB
LINK /MTF/MTFLD.FTN /MTF/MTF.LIB
LINK /MTF/PREDICT.FTN /MTF/MTF.LIB

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APPENDIX E. TEST PLAN

1.0 SUMMARY

1.1 BACKGROUND

Previous work at the Naval Postgraduate School describes a system for laser spot profile analysis using TV cameras to view the spot of a laser designator for the evaluation of the laser performance (ref 1, app B). This report also describes a proposed field test program for the system.

1.2 OBJECTIVES OF TESTS

The first objective of this test is to compare C_n^2 data produced by the NPS mechanical scanner and a video measurement system over a coincident atmospheric path. The second objective of this test is to apply the C_n^2 data to the evaluation of a ground-based laser designator.

2.0 DETAILS OF TEST PLAN

2.1 EQUIPMENT SETUP

The general setup is shown in figure 1, which is a block diagram of the optics. At one end of the range would be the designator, slit-scan OTF measurement system of the NPS, and a TV MTF measurement system. The target screen would be placed about 1 to 3 kilometers toward the other end of the range. The screen is viewed by a silicon vidicon. Finally, there is a small HeNe gas laser behind the screen, shining through a small hole in the screen. This is the source for the two OTF measuring systems.

In the first step, field measurements would be made with a strapped-down laser designator with its spot trained onto a uniform target screen. The designator must be securely strapped down so that any vibrations caused by wind or personnel walking about would not deflect the designator beam by more than 5 microradians. (One microradian maximum would be desirable.) This may require mounting the designator on a separate platform. These measurements would serve to determine the stability of the designator laser and optical system by separating the atmospheric turbulence effects from the overall effects. The beam deflection, due to atmospheric effects, is of the order of 20 to 30 microradians on a turbulent day. The telescopes with the slit-scan and TV must also be strapped down and mounted on the separate platform.

This separate platform can be constructed next to the main platform, but not actually attached to it. Thus, one can reach the equipment on the platform to work on it, but vibrations on the main platform will not affect the instruments on the separate platform.

For the same reason, the target screen should also be tied down so that the wind will cause motion of no more than approximately 1 cm motion maximum. The size of the target screen of 8 by 8 feet should be large enough to contain the laser spot under the most turbulent conditions at a distance of 1 to 3 kilometers from the designator. The reflectivity of the screen should be uniform for this part of the test.

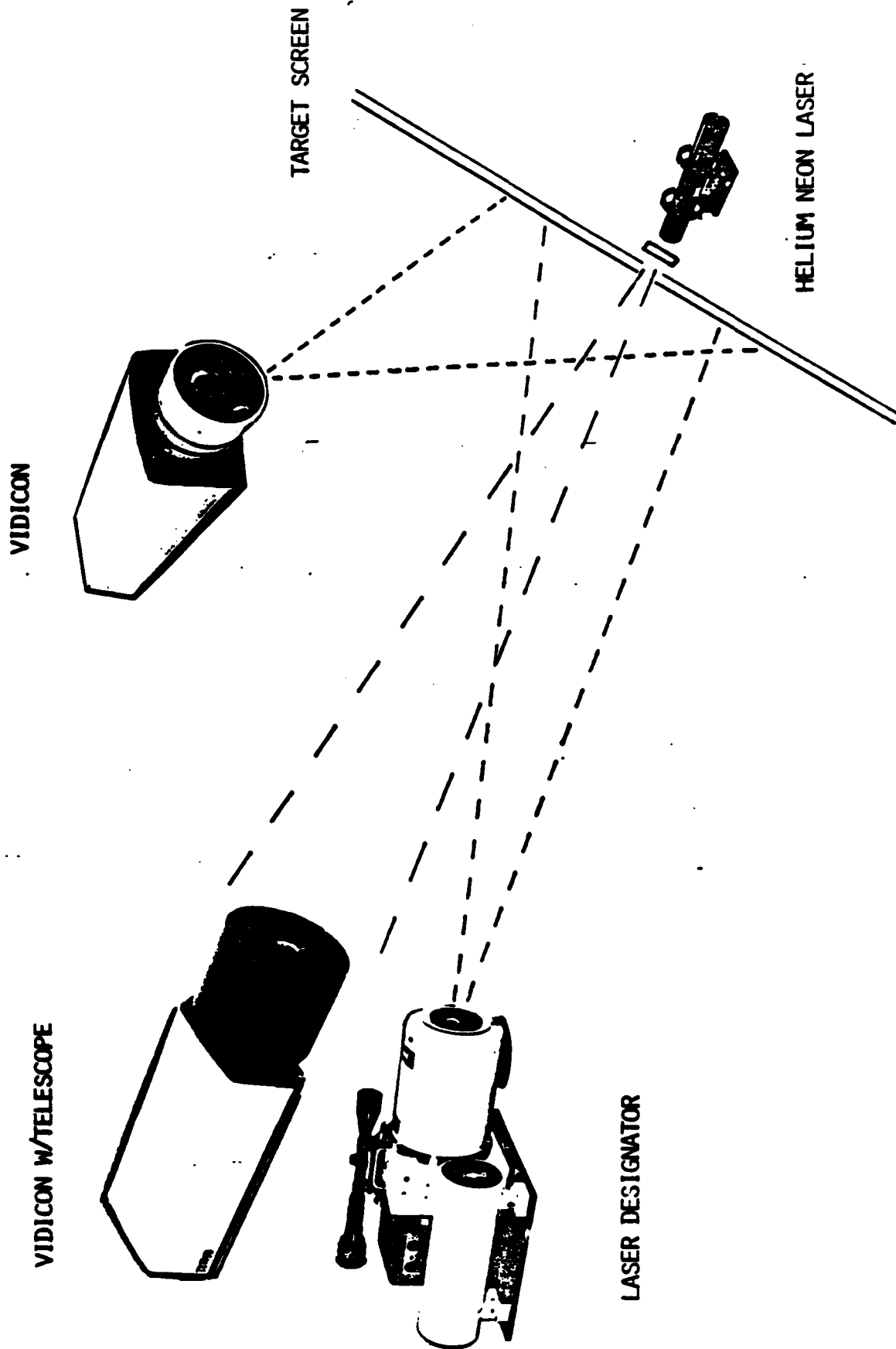


Figure 1. Optical Configuration for Field Test

A low power (1 mW) HeNe laser will be placed behind the middle of the target screen with a small hole in the screen to let the laser beam through. This HeNe laser will be directed toward the slit-scan and TV system located near the designator. The HeNe laser may need a small lens to diverge the beam a few milliradians so that the telescope will be uniformly illuminated.

The TV MTF system consists of an 8-inch Celestron telescope with a barlow lens of focal length -15 cm to increase the effective focal length of the telescope. A 0.6328 micrometer narrow band interference filter will be placed just in front of the vidicon between the vidicon and the telescope. An adaptor must be constructed to mount the TV onto the telescope. This adaptor contains the barlow lens and the interference filter. The dynamic range of a vidicon tube is not very large and the light cannot be changed by means of stooping down the aperture, without affecting the OTF of the system. Thus, there should be a way of inserting neutral density filters in front of the vidicon. This system, excluding the adaptor, will be supplied by Fort Huachuca. The adaptor will be made by the Naval Postgraduate School.

A second vidicon is needed to view the target screen. It must have a silicon focal plane in order to be sensitive at 1.06 micrometer, near infrared (IR), wavelength of the designator. It will be placed near the target screen along the line between the designator, but slightly off that line to avoid obscuring the screen from the designator location. This vidicon will have a 1.06 interference filter mounted in front of the lens to block out the background radiation from the sun. The synchronizing signal for this vidicon will be used to trigger the designator so that it will fire during the flyback time between the frames of the TV.

The output from each of the two vidicons will be recorded on separate panasonic TV tape recorders for later processing. The output of the NPS slit-scan telescope can be processed immediately. It will also be recorded on a Precision Instrument Co. FM analog tape recorder for later processing.

2.2 SUPPORT REQUIREMENTS

Each end of the range will require 115 Vac. The designator end will require approximately 20 amperes while the target end will require approximately 10 amperes. The power at the target end could be supplied by a small gas-powered generator set of approximately 1 or 2 kW power.

The test will require a simple communication system between the designator end and the target end. This could be a field telephone or walky-talky radios. Also, communication to the laboratory or Greely Hall would be useful.

The setting up of the equipment and the taking of data should easily be accomplished by four or five individuals. Two will be from the Naval Postgraduate School and the others from Fort Huachuca. During the taking of data two or three people will be needed at the main platform to take data on the NPS equipment and the TV-OTF system. The other two people will be at the target end operating the TV that views the spot.

2.3 SCHEDULE OF EVENTS

The equipment will be set up on the first day and tested for proper operation. This includes alignment and focusing the telescopes. The alignment of the secondary mirror of each telescope is very important for accurate measurements of the MTF. The silicon vidicon will be focused on the target screen from a distance that allows the target screen to just fill the field of view of the camera. A vertical scale (this could be a meterstick) is temporarily attached to the target and a recording is made of the video to give a scale in TV lines per meter of target screen. This will be required for later processing. If the distance between the TV camera and the screen is changed, this measurement will have to be repeated. The MTF of this vidicon should be checked by placing a video test pattern on the target and measuring the quality of the TV image.

Assuming everything is set up, aligned, and tested by evening, the first measurements with the OTF systems will be made at sunset which is the period of least turbulence. This will give an approximate calibration for all systems until a laboratory-controlled calibration can be made.

The NPS slit-scan OTF system will make measurements every half hour during the evening to get a plot of the optical turbulence structure function, C_n , as a function of time during the evening. At the same time, measurements will be made with the TV MTF system and recorded. During a period of time when the optical turbulence is low, the scale of the TV system will be determined by using a grating in front of the TV telescope. This calibration should remain fixed unless the focal length of the telescope system is changed.

It may be necessary to use the next day to complete the equipment setup and to make the preliminary tests described above.

One day should be devoted to taking data with the three systems. This will consist of taking a 1-minute recording of the video from each TV system and the NPS MTF system simultaneously. These measurements should be made at half-hour intervals throughout the day and evening. This is to demonstrate that the three systems are tracking each other; that is, they are measuring essentially the same optical turbulence and not some other systematic behavior. If the software for the data processing is in operation at this time, some of the data should be processed for numerically checking the results of the three systems. However, a qualitative check can be made at the time of each recording by measuring the image spread directly on the TV monitors. The spreading is almost proportional to C_n . (It is closer to $C_n^{1.2}$.)

If smoke tests are to be made, they should be conducted the following day. The smoke grenades should be set off up-wind at such a position that the smoke will drift across the optical path at several different ranges, e.g., 0.1, 0.3, 0.5, 0.7, and 0.9 of the distance from the optics end to the target end. One series of tests should be conducted during the daylight hours and one series of tests after sunset. Several minutes of recording of each of the three systems should be made during each of the smoke tests as the smoke passes through the optical path. Dugway Proving Ground will provide the equipment and personnel needed for the smoke test.

The last day is to be used for repeating any tests that seemed to give unexpected or inconsistent results. This should allow time to disassemble the equipment and pack it for transportation.

2.4 DATA ANALYSIS

The NPS data can be processed at the time the data is taken to obtain a C_n value. However, it will be recorded so that it can be reprocessed at a later date if there are any questions about the results of the other systems and how they compare with the NPS system.

The processing of the data from the two TV systems will be similar but not identical. Ten seconds of data from the recording of the 0.6328 TV data will be transferred to the Eigen video disk recorder. This is 300 frames, which is the maximum it will hold. Each frame will be transferred to the Quantex for digitizing. The digital data will then be transferred to the HP-1000, where it will be processed similar to the processing used by the NPS slit-scan system to obtain a C_n value. Several consecutive 10-second periods may be needed for longer averages, especially for determining the spectrum of the wander.

The processing of the data from the 1.06 TV system will also use the Eigen video disk recorder to capture 10 seconds of video, or 300 frames. However, the Quantex will subtract one frame of background from another frame of the spot before sending the data to the HP-1000. The processing here will use the subroutines of the prediction program PDT to calculate the C_n .

Most of the software has been written for other computers and needs to be translated to the FORTRAN used by the HP-1000. This will be completed before the test, but may not be debugged on the HP-1000 by then.

APPENDIX F. METHODOLOGY INVESTIGATION PROPOSAL AND DIRECTIVE



DEPARTMENT OF THE ARMY
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005

REPLY TO
ATTENTION OF

DRSTE-AD-M

17 OCT 1983

SUBJECT: RDTE Methodology Improvement Program Directive, Field
Validation of MTF Measurement, TECOM Project
No. 7-CO-RD4-EP0-006

Commander
US Army Electronic Proving Ground
ATTN: STEEP-MT-T
Ft. Huachuca, AZ 85613

1. Reference TECOM Regulation 70-12, dated 1 June 1973.
2. This letter and attached STE Forms 1188 and 1189 (Encl 1) constitute a directive for the subject investigation under the TECOM Methodology Improvement Program 1W665702D625.
3. The MIP at Enclosure 1 is the basis for headquarters approval of the subject investigation.
4. Special Instructions:
 - a. All reporting will be in consonance with paragraph 9 of the reference. The final report, when applicable, will be submitted to this headquarters, ATTN: DRSTE-AD-M, in consonance with Test Event 570/580. Each project shall have a phase/project completion in FY84 which is reflected in the scheduling in attached STE Forms 1188 and 1189.
 - b. Recommendations of new TOPs or revisions to existing TOPs will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as part of the report approval process.
 - c. The addressee will determine whether any classified information is involved, and will assure that proper security measures are taken when appropriate.
 - d. Upon receipt of this directive, test milestone schedules as established in TRMS II data base will be reviewed in light of known other workload and projected available resources. If rescheduling is necessary, a letter citing particulars, together with recommendations, will be forwarded to Commander, US Army Test and Evaluation Command, ATTN: DRSTE-AD-M, with an information copy to DRSTE-TO-O, within 15 calendar days.

17 OCT 1983

DRSTE-AD-M

SUBJECT: RDTE Methodology Improvement Program Directive, Field
Validation of MTF Measurement, TECOM Project
No. 7-CO-RD4-EPO-006

e. The HQ, TECOM point of contact is Mr. Norman E. Pentz, ATTN:
DRSTE-AD-M, AUTOVON 283-2170/2375.

f. FY84 RDTE funds in the amount of \$50,000 have been authorized for this
investigation, DARCOM Form 1005 will be forwarded by the Comptroller.

FOR THE COMMANDER:



GROVER H. SHELTON
C, Meth Imprv Div
Analysis Directorate

1 Encl
as

June 1983

METHODOLOGY INVESTIGATION PROPOSAL

1. TITLE. Field Validation of TECOM's Path-Weighted MTF Determination for EO and DEW Systems

2. CATEGORY. Modern Weapons, Smart Munitions

3. INSTALLATION. US Army Electronic Proving Ground
Fort Huachuca, AZ 85613

4. PRINCIPAL INVESTIGATOR. Colin Giorgi
Test Operations Office, MTD
Steep-MT-T
AUTOVON 879-6016

5. STATEMENT OF THE PROBLEM. The distribution of the refractive index structure coefficient, C_N^2 , along an atmospheric optical path significantly affects laser beam quality, infrared signatures and the effectiveness of laser directed energy weapons (LDEW). Although the feasibility of a TECOM conceived procedure for measuring the properly path weighted MTF from which the path weighted C_N^2 integral can be calculated, has been demonstrated in the laboratory, its validity under field test conditions has not.

6. BACKGROUND. The degrading effects of atmospheric turbulence on the performance of beam forming and imaging optical systems have been well known for many years. Measured variances in laser beam intensity, position, and spot energy distribution have been quantitatively correlated to the degree of turbulence along the relevant optical path. During the 1960's, work by several investigators, notably Fried, established the theoretical relationship between the atmospheric modulation transfer function (MTF) and the square of the refractive index structure coefficient C_N^2 . Subsequently, other workers developed the theoretical relationship between C_N^2 and laser beam degradation/distortion by the atmosphere. The MTF generally provides a measure of optical image integrity remaining after passage over an optical path while C_N^2 is a measure of the atmospheric turbulence along the path. Thus, from a measurement of either C_N^2 or the MTF, both image quality and laser beam quality can be derived. Because of the critical time and specific path sensitivity of the turbulence characteristics, existing methods for measurement of C_N^2 such as scintillometry were deficient in establishing the true path turbulence structure affecting a test item's/system's performance. To resolve this deficiency, the Naval Postgraduate School (NPS) developed a mechanical slit scanning technique which directly provides the MTF from which the properly path weighted C_N^2 can be derived. Also, whereas the scintillometer precision exceeds an order of magnitude of the measurement itself, the NPS system is precise within approximately 10%. During the review of the NPS work by the TECOM Laser Technical Committee, it was determined that a video camera could replace the slit scanning arrangement and the MTF could be determined by the video image analysis technique already established at WSMR and YPG. This would provide a real time

MTF measurement. As a result a methodology investigation was initiated at USAEPG to develop this video adaptation. The NPS was employed as contractor to do the actual work which was completed as far as demonstrating that in the laboratory, the video technique provides essentially the same results as the NPS mechanical slit scanning equipment. To complete this work, a field validation test is required.

7. GOAL. To validate a TECOM conceived method for measuring the MTF in real time along the optical path involved in the field test of any electro-optical (EO) or directed energy weapon (DEW) system and thereby determine the effects of the atmosphere on system performance.

8. DESCRIPTION OF INVESTIGATION.

a. The validity of TECOM's real time, video based measurement of the MTF along an atmospheric optical path will be investigated by a field test/comparison of results obtained with those obtained using the NPS mechanical slit scanning equipment.

b. USAEPG personnel will:

(1) Develop a field test configuration and identify all instrumentation not currently available but required for the field validation of the TECOM real time MTF measurement procedure. The configuration will be that appropriate for the testing of a laser designation system. The standard will be the static MTF measurement system developed by the NPS.

(2) Procure or obtain on loan all equipment required but not available at USAEPG.

(3) Measure the path weighted MTF a statistically significant number of times using concurrently both the TECOM procedure and the NPS procedure along as nearly identical optical paths as feasible. Contractor assistance may be required.

(4) Adapt and utilize the image analysis software developed at WSMR, YPG, NPS, or equivalent to reduce the data for determination of the properly path-weighted C_N^2 integral.

9. JUSTIFICATION.

a. Association with Mission. TECOM has the responsibility to measure the performance of varied types of EO systems including laser DEW. Optical turbulence is one of the major causes of EO system degradation and should be properly measured during tests to enable a valid performance assessment of the EO test item.

b. Present Capability, Limitations, Improvement, and Impact on Testing if not approved. TECOM can currently use scintillometry or task another organization to use the NPS system for optical turbulence assessment. Both of these

methods are undesirably limited. This video capability will enable a precise, convenient, and sensitive determination of the effects of the atmosphere on EO system performance. If the investigation is not completed, the effects of optical turbulence during many laser or other EO system performance tests will not be separable from the data.

c. Dollar Savings. Dollar savings for testing per se are not quantifiable since MTF data using existing methods have largely been unusable.

d. Workload.

Test Program	FY 85	86	87	88	89
Remotely Piloted Vehicle	X	X			
STINGRAY	- - - -	-Classified	- - - -	- - - -	- - - -
CCLAW	- - - -	-Classified	- - - -	- - - -	- - - -
ELOCARS		X			

10. RESOURCES.

a. Financial.

	Dollars (Thousands)	
	FY84	
	<u>In-House</u>	<u>Out-of-House</u>
Personnel Compensation	9.0	
Travel	3.0	
Consultants and Other Services		30.0
Materials and Supplies	3.0	
Equipment	<u>5.0</u>	<u> </u>
Subtotals	<u>20.0</u>	<u>30.0</u>
Total	50.0	

b. Explanation of Cost Categories.

(1) Personnel Compensation. Covers in-house labor costs for the principal investigator and other project support personnel.

(2) Travel. Travel is required to coordinate the task with other TECOM installations. Travel in FY84 may be revised if the field testing is scheduled for WSMR or YPG.

(3) Consultants and Other Services. Consultant support will be utilized to assist in performing the detailed technical feasibility analysis and to evaluate the field test data.

(4) Materials and Supplies. Recording media and incidental supplies will be required to support the field testing.

(5) Equipment. The empirical verification field tests will require a designator source. Current shortage of fielded items or spare test items indicates that a simulator unit will have to be procured. FY84 funding covers equipment contingencies including servicing and repair.

c. Anticipated Delays. A delay in EPG's acquisition of a laser may extend the initiation of the field verification testing. However, an alternate support capability may be made available at WSMR or YPG to alleviate the problem.

d. Obligation Plan (FY84).

	<u>FQ</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>TOTAL</u>
Obligation Rate (Thousands)		3.0	28.0	10.0	9.0	50

e. In-House Personnel.

(1) Requirements.

	<u>Number</u>	<u>FY84 Manhours Required</u>	<u>Available</u>
Physicist, GS-1310	1	250	250
Elec Engr, GS-0855	1	250	250
Total		500	500

(2) Resolution of Non-available Personnel. Not applicable.

11. INVESTIGATION SCHEDULE.

						<u>FY84</u>						
	O	N	D	J	F	M	A	M	J	J	A	S
In-house	-	-	-	-				-	-	-	-	R
Contract		A	:	:	:	:	:	:				

Symbols: - - - Active investigation work (all categories)

. . . Contract monitoring (in-house only)

A Award of Contract

R Final report due at HQ, TECOM.

12. ASSOCIATION WITH TOP PROGRAM. It is expected that the turbulence measurement methodology initially developed for specific commodity items such as laser designators and rangefinders will be incorporated into the existing TOP's covering those items. As more generalized procedures are developed that apply to a broad class of E-O test items, then a new TOP will be generated that can be referenced in the E-O commodity item TOP's.

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APPENDIX G. REFERENCES

1. Crittenden, Cooper, Milne, Rodeback, Armstead, Kalmbach, Land, and Katz; Optical Resolution in the Turbulent Atmosphere of the Marine Boundary Layer, Naval Postgraduate School Report, NPS61-78-003, February 1978.
2. Crittenden, Cooper, Milne, Rodeback, Kalmbach, and Armstead; Effects of Turbulence on Imaging Through the Atmosphere, SPIE Proceedings, 142, 130, March 1978.
3. Crittenden, Cooper, Milne, Rodeback, and Kalmbach; Multiwave Extinction and Index Fluctuation Measurements, AGARD Proceedings, No. 300, 13, 6 April 1981.
4. Fried, D. L.; Optical Resolution through a Randomly Inhomogeneous Medium for Very Long and Very Short Exposures, Journal of the Optical Society of America, 56, 10, 1372, 1966.
5. Crager, Scott R.; A Computer Program for Investigating Atmospheric Effects on Laser Designators, M. S. Thesis, Naval Postgraduate School, March 1982.
6. Connor, John; Analysis of Turbulence Utilizing a Video Tape Recorder and Digital Storage Oscilloscope, M. S. Thesis, Naval Postgraduate School, December 1982.
7. Crittenden, E. C. and Milne, E. A.; System for Laser Spot Profile Analysis, Naval Postgraduate School Report NPS61-83-007, May 1983.
8. Crittenden, Milne, Crager, Connor, Pentz, Decker and Giorgi; Optical Turbulence Measurement-Investigation for Analysis of Laser Designator Spot Patterns - Phase I, USAEPG Report-FR-1226, May 1983.

<u>Addressee</u>	<u>Number of Copies</u>
Commandant Naval Postgraduate School ATTN: Code 61Mn (Dr. E. A. Milne) Monterey, California 93940-5000	2
Commander US Army Electronic Proving Ground ATTN: STEEP-TM-AC Fort Huachuca, Arizona 85613-7110	4
US Army Atmospheric Sciences Laboratory ATTN: DELAS-SY-S White Sands Missile Range, New Mexico 88002-5000	1
Director NOAA/ERL/APCL R31 RB3-Room 567 Boulder, Colorado 80302-5000	1

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